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ELEMENTARY PHYSICS

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PREFACE

The purpose of this book is to make the pupil acquainted with the more elementary facts of physics and physical chemistry, to give some idea of methods of experimentation, to illustrate the drawing of conclusions from experiments and observations, and to show that theories are merely attempts to explain, by means of certain suppositions, various phenomena whose existence is unquestioned but whose nature can not be more satisfactorily explained by other means.

In order to secure these results within the time usually devoted to physics in a high-school course, it is necessary to limit the number of phenomena selected for study. In this selection we have been influenced not only by the desire to choose those phenomena most worthy of study, but also by the necessity of confining the choice to those phenomena which admit of a logical treatment within the limits of this book. It is considered inexpedient to attempt to include all matters of popular interest. If the material here selected does not fully occupy all the time of the pupil, the teacher may with profit add a discussion of various other subjects of direct interest to his immediate community. The arrangement of this material in chapters is due to the following considerations.

Many of the phenomena shown by gases and liquids

may be illustrated by means of very simple apparatus. Their explanation is usually simple and does not involve the use of theories. For this reason their study is especially adapted to serve as an introduction to methods of experimentation and direct reasoning.

Next we endeavor to show that various phenomena, otherwise inexplainable, can be understood if a certain theory be accepted. A theory, in order to be of any real service, must rest upon a very good basis of judiciously observed facts. For this reason we believe that, before a theory is advanced, there should be presented a series of phenomena which can be explained only by means of that theory.

For instance, in the second chapter, in order to make clear the need of the Molecular theory, we discuss certain of the more elementary phenomena of heat, diffusion, osmosis, evaporation, solution, and crystallization, and show that a comprehension of these phenomena is materially assisted by the Molecular theory. This is followed in the third chapter by a more extended account of those phenomena of heat which can be explained by the use of the Molecular theory without the addition of the Ether theory.

The fourth chapter includes the study of the Atomic theory, the foundation of chemistry. This theory demands greater powers of imagination. It is not possible in support of it to produce so many simple experiments, easily performed and easily understood, which show the connection between the phenomena considered and the theory by means of which they can be explained.

The fifth chapter takes up enough of the subject of sound to bring out the idea of vibrations and of waves.

This idea is utilized in the sixth chapter, which is especially devoted to a consideration of the Ether theory. This is one of the most abstruse theories of science. Special emphasis should be placed, therefore, upon the reasonableness of this theory as a true explanation of the facts. The phenomena studied are those of radiant energy. In the treatment of this subject as little distinction as possible is made between those vibrations of the ether which produce both heat and light and those which produce only heat.

The Molecular, Atomic, and Ether theories are attempts to get at the facts underlying the phenomena considered. The result is that most physicists believe in the actual existence of molecules, atoms, and the ether, although they may not have clear conceptions of the form in which they exist.

Lines of Force (seventh chapter), as used to explain the phenomena of Magnetism, are excellent examples of what may be called merely useful conventions. No physicist believes in the actual existence of these Lines. To him Lines of Force represent merely the *directions* in which the magnetic forces act. Nevertheless, these conventions have proved very useful in the correlation of widely different phenomena of magnetism and electromagnetism.

A very useful theory for which there is almost no foundation is the Theory of Gravitation (eighth chapter). While it has been known in all ages that an apple will

fall to the ground, and that it falls with a certain increase of velocity, it is by no means certain that the earth actually attracts the apple.

We hope that the book will serve as an introduction to present methods of scientific thought and research. It is descriptive in character. The experiments discussed should all be performed. In most cases it will be sufficient if the experiments are performed by the teacher before the class. To these experiments may be added many others which should be performed by the pupil. In order to be of educative value, most of the experiments performed should be chiefly quantitative, although readily within the mental grasp of the pupil. Since the nature of these additional experiments must depend very largely upon the equipment at hand in each school, their selection may be left to the individual teacher. The list of laboratory experiments accepted for entrance by the association of colleges will be found very suggestive.

The first four chapters may be taught with profit in the first half of the first year in high-school. They include most of the facts in physics which teachers in botany, physiology, zoology, physical geography, and chemistry like to have their pupils know before they enter upon these special subjects. Teachers in these various sciences find the time allotted to their subject too brief to enter upon a full discussion of the physical phenomena involved, and also are confronted by the necessity of taking up physical phenomena in the order in which they occur in the text-books devoted to their own work. As a result, their treatment of the physical phenomena is

often very inadequate and even illogical, and in consequence the pupil does not get clear conceptions of the points in question. It is, therefore, better to present the physical phenomena which are of use in explaining the facts of other sciences first at greater length, in their proper general relationship with other physical phenomena. In this manner their special significance in explaining the various phenomena studied in other sciences will gain in clearness and force.

In the preparation of this book we have utilized every available source. We wish especially to express our indebtedness to Miss Elizabeth G. Evans for suggestions in connection with the text and for assistance in reading the proof-sheets.

STEELE HIGH SCHOOL, DAYTON, OHIO,
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ELEMENTARY PHYSICS

CHAPTER I

GASES AND LIQUIDS

1. Air Fills Many Spaces Apparently Empty.—Insert a lamp chimney vertically half way down into water (Fig. 1). How does the height of the water within the chimney compare with the height of the water on the outside?

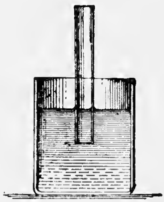


Fig. 1.

Hold in your hand an empty tumbler; that is, a tumbler which does not contain anything that can be seen. Is it really empty, or is it full of some invisible material? To determine this, place the tumbler, mouth downward, half way under the surface of the water in a glass jar (Fig. 2). Something in the tumbler prevents the water from rising as high within the tumbler as the level of the water in the jar. This is the air which is present in the tumbler. The water presses up against the air and slightly compresses it. At the same time the condensed air presses down and prevents the intruding water from rising within the tumbler more than a short distance above the mouth.

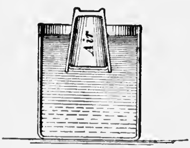


Fig. 2.

In the case of the lamp chimney, neither end is closed, hence, as the chimney sinks into the water, the air is pushed out at the top. The water

therefore rises in the chimney to the level of the water in the jar outside of the chimney.

2. Gases Have Weight.—Beneath one of the pans of a delicate balance attach a hollow brass globe supplied with a stop-cock, by means of which the passage leading to the interior of the globe can be either opened or closed. Upon the other pan place a sufficient number of weights or of shot to make the beam of the balance perfectly horizontal. In other words, *counterpoise* the globe.

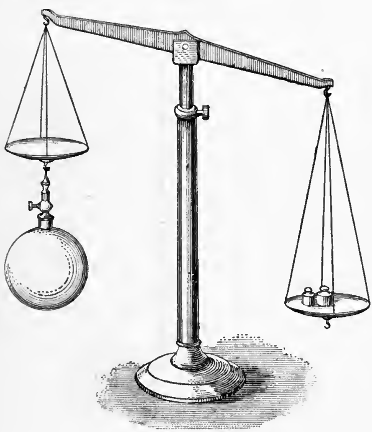


FIG. 3.

Then, without changing the weights, remove the brass globe, pump out the air, close the stop-cock, and return it to its former position beneath the pan. The side of the balance to which the globe is attached now rises, showing that there has been a loss in weight on this side of the balance (Fig. 3). Since the only material removed from this side of the balance is the air which was pumped out of the globe, the loss in the weight of the globe can be due only to the removal of the air within it. Therefore air has weight.

If the globe had been filled with hydrogen or carbon dioxide, instead of air, it would have been found that these gases also have weight, but that hydrogen is lighter and carbon dioxide is heavier than air.

3 Additional Experiments Proving that Gases have Weight.—That air, hydrogen, and carbon dioxide differ

in weight can be shown also by a modification of the preceding experiment. Make an open paper box, about four inches square and four inches deep, and by means of strings attach it, open end upward, beneath one of the pans of the balance. A paper oyster-bucket will be excellent for this purpose. Counterpoise it with weights in the other pan. The bucket, of course, is full of air.

Pour carbon dioxide (§ 139), which is an invisible gas, into the bucket. The carbon dioxide, which is heavier than air, pushes out the air and takes its place. The side of the balance to which the bucket is attached at once goes down (Fig. 4). Tip the bucket so that the carbon dioxide can run out and its place is once more taken by air. The beam again becomes horizontal. Carbon dioxide evidently has a greater weight than air.

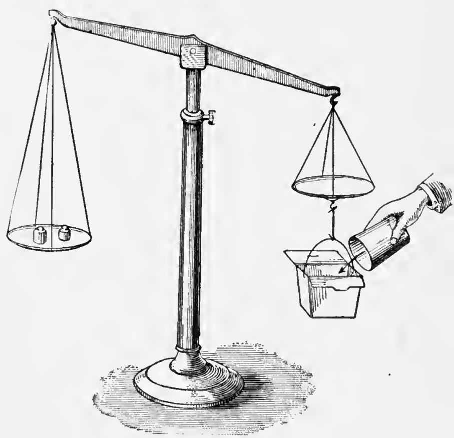


FIG. 4.

Hang the bucket, with the open end downward, beneath the same pan of the balance. In order that an open vessel may retain hydrogen (§ 137) it must be kept mouth downward. Place the mouth of the vessel containing the hydrogen beneath one edge of the bucket; turn the vessel as if attempting to pour something upward (Fig. 5). The lighter hydrogen runs up into the bucket and pushes down the heavier air until it is entirely replaced by hydrogen. The side of the balance to which the bucket is attached rises.

Therefore the bucket is filled with a gas lighter than air.

4. Principles Involved in Pouring of Gases.—When water is poured into a tumbler, it sinks to the bottom and pushes out the lighter air. In the same manner, when carbon dioxide is poured into the paper bucket, it sinks to the bottom and pushes out the air.

When a tumbler containing air is placed in water open end downward the water is not able to displace the air. In the same manner, when a vessel containing hydrogen is held with the open end downward, the heavier air surrounding the vessel is not able to push out the lighter hydrogen.

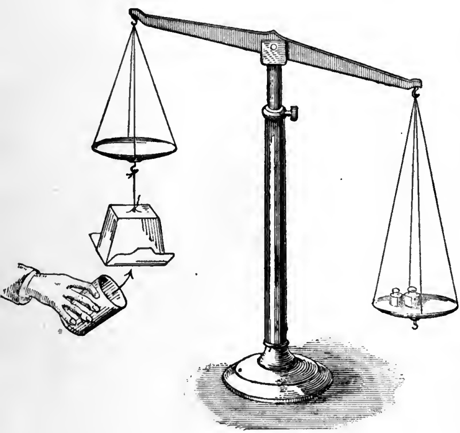


FIG. 5.

If the tumbler containing air had been placed in the water with the open end upward, the water would have rushed into the vessel and crowded out the air. In the same manner, as soon as a vessel containing hydrogen is turned until the open end faces upward, the heavier air runs into the vessel and pushes out the lighter hydrogen.

Place the tumbler in water so as to permit the air to escape. The tumbler is now full of water. Invert the tumbler, and hold it under the water in this inverted position. Plunge a vessel, containing nothing but air, mouth downward into the water and bring its mouth beneath one edge of the tumbler. Turn the vessel so

that the air can escape upward into the tumbler and entirely fill it. In the same manner, if the paper bucket be suspended with the open end downward, and a vessel containing hydrogen, mouth end downward, be brought near the bucket, so that the mouth of the vessel be beneath one edge of the bucket, the vessel can be turned so as to permit the lighter hydrogen to run up into the bucket and push out the heavier air.

All gases are not invisible. Some of them have very characteristic colors. Chlorine has a yellowish-green tint. Nitrogen tetroxide and bromine have different shades of reddish brown. The methods of obtaining all of these

FIG. 6.

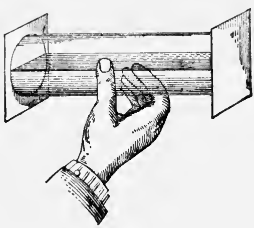


FIG. 7.

gases can be learned easily from any good work on chemistry.

5. Air Presses in All Directions.—Hold a piece of blotting-paper or pasteboard over the mouth of a tumbler filled with water and shake the tumbler until the paper is thoroughly moistened. Then invert the tumbler (Fig. 6). What holds the blotter in place, so that the water can not run out? In what direction is the air pressing? Hold the tumbler so that the mouth will face sidewise. Does the water run out? In what direction is the air pressing now?

Place an argand-lamp chimney under water, press a

piece of blotting-paper tightly against each end, and remove the chimney from the water. Now carefully remove the hands from the blotting-paper at both ends of the chimney and hold the chimney in a vertical position. Why does the water not run out? Hold the chimney in a horizontal position (Fig. 7). Hold it in other positions. In what direction is the air pressing in these different cases? Notice that the air is pressing on both ends of the chimney. Indeed, it is pressing also on the walls of the chimney, but the walls are too strong to give evidence of this pressure.

6. Effect of Inequality of Air-Pressure.—The pressure of the air can be further illustrated by the following experiment. Tie a small piece of sheet rubber over the top of a bladder-glass and place the glass on the plate of an air-pump. As soon as part of the air is pumped out of the glass, the pressure of the air beneath the rubber is less than the pressure of the air above, and the rubber is forced down into the glass (Fig. 8). Remove the rubber and close the opening at the top of the bladder-glass firmly with the palm of the hand. Pump out all or nearly all of the air. The hand now is forced down so strongly against the glass, that it cannot be easily withdrawn. What is forcing it down?

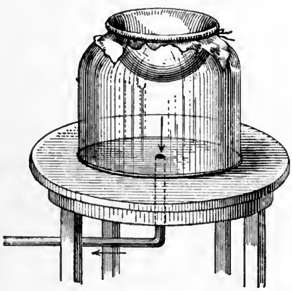


FIG. 8.

At the beginning of the experiment the pressure of the air within the vessel and the pressure of the air surrounding it is the same. As soon as a part of the air is pumped out of the vessel, the pressure of the air *remaining within* it becomes less than the pressure of the whole quantity

of air which was originally present. In consequence it becomes less also than the pressure of the *air surrounding the vessel.* The hand is forced down with a force equal to the difference between the pressures exerted by the air within and without the vessel. When the air is once more admitted to the bladder-glass the pressures are equalized and the hand may be readily removed.

Instead of a bladder-glass, a small lantern globe may be used. In this case the ends of the globe should be ground smooth by rubbing them over a piece of plate-glass covered with a thin layer of fine emery powder moistened with water.

Press most of the air out of the thin rubber bag attached to a toy whistle; close it tightly, and place it beneath a bell-jar (receiver) on the plate of an air-pump. The base of the bell-jar, where it rests upon the pump plate, should be rubbed with tallow to make it air-tight. Pump out of the bell-jar the air which surrounds the rubber bag. Why does the rubber bag dilate as the air around it is gradually removed?

7. Vacuum Fountain.—The vacuum fountain apparatus consists of a tall glass vessel open only at the base. From this base a narrow, tapering brass tube extends several inches up into the interior of the vessel, and ends with a small opening. The base of the apparatus is provided with a screw thread, so that the vacuum fountain vessel can be fastened, in an upright position, on the plate of an air-pump. The entrance to the tube through this base can be opened or closed by means of a stopcock.

Fasten the vacuum fountain vessel on the plate of an air-pump. Remove nearly all of the air. Close the stopcock. Place the lower end of the vessel beneath the sur-

face of the water in a glass jar. Open the stop-cock. The water is forced up into the vessel in the form of a tiny spray like a fountain (Fig. 9). Explain. In the figure the vessel is represented as if screwed into a support which permits the ready entrance of water from beneath. This makes it unnecessary to hold the apparatus during the latter part of the experiment.

Fill a quart bottle about one-

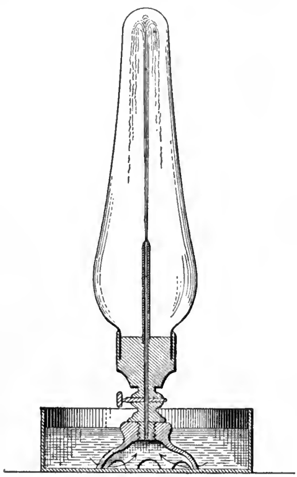


FIG. 9.

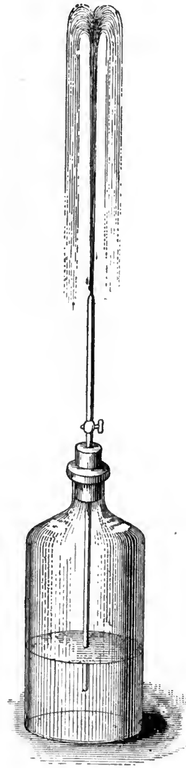


FIG. 10.

third full of water. Rotate in the flame of a Bunsen burner one end of a piece of glass tubing, about ten inches long, until the opening at this end becomes very small. Thrust the other end through the hole in a rubber stopper placed in the mouth of a quart bottle, so that the lower end of the glass tube is within a short distance of

the bottom of the bottle. Through the glass tube blow vigorously into the bottle for a short time, and then remove your mouth quickly. What causes the fountain (Fig. 10)? In the drawing the glass tube is replaced by a brass tube supplied with a stop-cock. The stop-cock is closed before the mouth is taken away.

Compare in these two experiments the relative pressures of the air within the vessel and the air without the vessel.

8. Water Held Up in a Tube by Air-Pressure.—By means of the thumb close a test-tube filled with water, invert it, and place the mouth of the test-tube a short distance beneath the surface of the water in a glass jar. Remove the thumb. Why does the water not run out of the test-tube (Fig. 11)? Because the pressure of the air on the surface of the water in the glass jar is sufficient to prevent this.

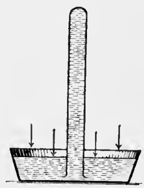


FIG. 11.

Is there any limit to the amount of pressure which the air exerts? If so, there must be a limit to the weight of water which the pressure of the air can hold up.

If, instead of the short test-tube, a stout tube 35 feet or more in length and closed at the top had been used, would the pressure of the air on the surface of the water in the vessel have been sufficient to hold up all of the water in the tube?

This has been tried, and it has been found that the pressure of the air, at sea level, is usually sufficient to hold up about 34 feet of water, but no more. It can, of course, hold up any height less than 34 feet. The water in a tube longer than 34 feet, therefore, falls until the upper surface of the water in the tube is about 34 feet above the surface of the water in the vessel (Fig. 12). If

the pressure of the air on the surface of the water in the vessel were greater, it could hold up a column of water having a greater vertical height. If the pressure of the air were less, the height of the column of water held up would be less (§ 29).

It is evident that the greatest height of water which can be held up in a long tube closed at the top can be used to determine the strength of pressure of the air on the water in the vessel. If we know the force with which the water in the tube is pressing downward, we also know the force with which the air must be pressing on the water in the vessel in order to prevent the water in the tube from escaping.

9. Amount of Pressure Exerted by Air.—If the area of the opening at the base of the tube is one square inch, and if the height of the water in the tube is 34 feet, or 408 inches, then the quantity of water in the tube is 408 cubic inches. It has been determined by actual weighing that the weight of one cubic inch of water is .036+ pounds. Then the weight of the total quantity of water present in the tube is $.036 \times 408 = 14.688$ (14.7) pounds. Therefore the water in the tube presses downward with the force of 14.7 pounds on the square inch of water at the base of the tube, and the air evidently presses downward on the surface of the water in the vessel with the same force (§ 12).

10. Height of Column Dependent upon Density of Liquid.—In the case of liquids heavier than water, the greatest height of the liquid which can be held up by this air pressure of 14.7 pounds on each square inch of surface must necessarily be less than 34 feet. Since mercury weighs 13.6 times as much as an equal volume of water, the highest column of *mercury* which can be held up by

the air-pressure of 14.7 pounds, is only $\frac{1}{13.6}$ or $\frac{10}{136}$ as high as the highest column of *water* held up by the same air pressure. This height is $\frac{10}{136}$ of 408 = 30 inches (Fig. 12).

In order to show the height of mercury which can be held up by air-pressure, take a stout glass tube more than 30 inches long and closed at one end; fill it with mercury, close the open end with the finger, and dip this end under the surface of some mercury in a small vessel. A broad salt-cellar is very convenient. Remove the finger. If the tube be held vertically, mercury will run out until the upper surface of the mercury in the tube does not rise over 30 inches above the level of the mercury in the vessel.

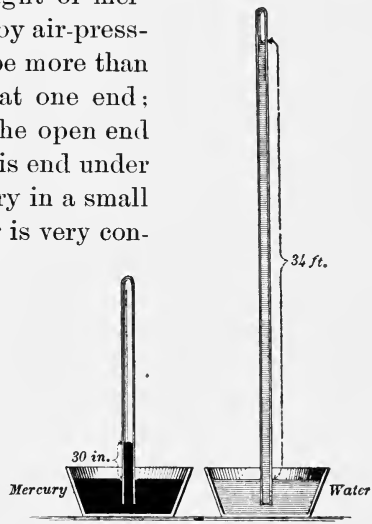


Fig. 12.

11. Height of Column Measured Vertically.—If the tube be inclined, mercury runs toward the closed end of the tube, so that a greater quantity of mercury is held up within the tube. If, however, the vertical distance from the surface of the mercury within the tube to the surface of the mercury in the vessel be measured, it will be found to be still 30 inches (Fig. 13). In other words, an air-pressure of 14.7 pounds per square inch can hold up mercury to the *vertical height* of 30 inches, irrespective of the variation in the *quantity of mercury* held up. If tubes of very different diameters be taken, it will be found that mercury can be held up to the same vertical height of 30 inches in all of these tubes;

although, of course, the quantity of mercury in the wider tubes greatly exceeds that in the narrow ones.

If now tubes, variously bent and varying in diameter, be dipped in vessels exposing different amounts of surface of mercury, it will be found that the same air-pressure can always hold up the same vertical height of mercury, irrespective not only of the form of the tube and its diameter, but also of the area of the mercury exposed in the vessel into which the base of the tube is dipped. Therefore, in determining the pressure of the air by means of the column of mercury held up in a barometer, it is customary to state that the pressure of the air is equivalent to the pressure of a column of mercury a certain number of inches or centimeters in height, and no mention is made of the diameter of the tube, the weight of the mercury which it contains, or of the area of the mercury exposed in the vessel. In other words, instead of stating that the pressure of the air is 14.7 pounds per square inch it is often stated that the pressure of the air is equal to 30 inches.

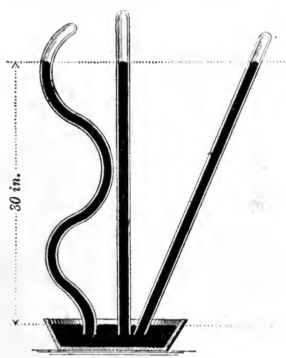


FIG. 13.

12. Amount of Air-Pressure on One Square Inch at Sea Level.—In the experiments just described, the pressure of the air is not 14.7 pounds on the entire surface of the mercury in the vessel, but 14.7 pounds on each square inch of that surface. An explanation of the reasons for this fact involves a knowledge of Pascal's Law (§ 53), and had best be deferred until that law has been studied. The fact that the pressure of air is 14.7 pounds on each

square inch can be demonstrated without a knowledge of Pascal's Law by the following experiment.

Suspend from a strong support, seven or more feet above the floor of the room, a short but broad brass cylinder, closed at the top, with the open end facing downward (Fig. 14 A). A movable brass plate, having an area of 26 square inches, fits air-tight at all levels within this cylinder. A small brass tube at the top of the cylinder permits the escape of most of the air when the plate is thrust to its highest position within the cylinder. A brass handle is attached to the lower surface of the movable plate. From the handle may be suspended, by means of a rope, a board such as is used for swings. Thrust the brass plate as far up in the brass cylinder as possible and permit the air to escape. With a pinch-cock close the rubber tube slipped over the top of the brass exit tube by means of which the air escapes, and, using boys, place as great a weight upon the swing-board as the apparatus will safely hold (Fig. 14 B). This total weight will be found to equal or exceed 260 pounds. The boys are evidently held up by the excess of pressure of the air against the lower surface of the plate, as compared with the pressure of the small quantity of air remaining in the cylinder above this plate. This demonstrates that the pressure of the air on

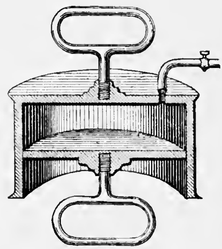


FIG. 14 A.

FIG. 14 B.

26 square inches either equals or exceeds 260 pounds. Therefore the pressure of air on each square inch equals or exceeds 10 pounds.

If a cylinder of larger diameter and a plate of larger area had been used, it would have been found that a correspondingly greater weight could have been held up by the air. By this means it can be demonstrated that there is a definite pressure of the air on every square inch, and that the total pressure of the air depends upon the total area of the surface exposed. If all the air above the plate in the cylinder had been removed by an air-pump, the total pressure of the air on the lower surface of the plate would, at sea level, have been found to be more nearly 14.7 pounds on each square inch.

13. Variation in Air-Pressure Due to Elevation.—A small quantity of air has only a slight weight, but, since the atmosphere extends for a distance of more than 100 miles above the earth, the total quantity of air overlying any square inch of the earth's surface is very great, and the pressure produced by that quantity of air on one square inch at the surface of the earth must be considerable. The pressure of the atmosphere upon any square inch of surface depends upon the total quantity of air directly overlying that surface. This quantity will be greater at the level of the sea than on the summit of a high mountain, in the bottom of a valley than at the top of a hill, at the base of a building than in one of its upper stories.

If the amount of pressure of the atmosphere on any surface be proportional to its height above sea level, it is evident that the pressure of the atmosphere upon that surface can be used to determine its elevation above the sea. This is so nearly true, when corrections are made

for temperature, especially when within moderate distances from the surface of the earth, that the degree of air-pressure on a square inch of surface at any locality has often been used as a means of determining its distance above sea level. The height of most mountains has been determined in this manner (§ 100). This method is especially useful where it is either too difficult or too expensive to determine the elevation by means of the more accurate methods used by the surveyor.

14. The Barometer.—The barometer is the instrument used in measuring atmospheric pressure. There are two kinds of barometers in ordinary use, the *mercurial* and the *aneroid.*

A glass tube usually 34 inches long, with a small bore (internal diameter) and very thick walls, and closed at one end, is filled with mercury. The open end is held shut by means of the thumb, and in this condition is inserted beneath the surface of some mercury placed in a small sized cup. The air-pressure on the mercury in the cup is not sufficient to hold up or balance the entire vertical height of mercury in the tube. It will be remembered (§ 10) that the height of mercury held up by the average air-pressure at sea-level, is only 30 inches (Fig. 15). Therefore the mercury in a barometer-tube 34 inches long will fall at least 4 inches at sea-level. If the barometer be carried to elevations above sea-level, the column of mercury in the tube gradually falls below 30 inches at the rate of 1 inch for a rise in elevation of about 910 feet. The height of the column of mercury in a barometer-tube

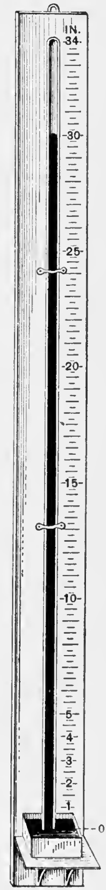


FIG. 15.

at any locality may therefore be utilized to determine its elevation above sea-level.

In order to determine approximately the height of the top of a mountain above its base (not above sea-level), ascertain the height of the column of mercury in a barometer-tube both at the top of the mountain and at its base and multiply by 910 the difference between the two heights expressed in inches. The product will be the height of the mountain expressed in feet. The heights of mountains are, however, given in geographies as so many feet above sea-level.

15. The Barometer as an Indicator of Changes in Weather. —Variations in the height of the barometer are also due to atmospheric conditions which cause changes in the weather. Such variations are especially noticeable at times preceding violent storms. In general it may be said that a rapid rise of the mercury in the barometer indicates fair weather and a rapid fall indicates stormy weather, including probably rain, sleet, or snow. A steady barometer indicates a continuance of existing conditions. The use of the barometer in determining variations in the weather can be studied with profit in some book on meteorology.*

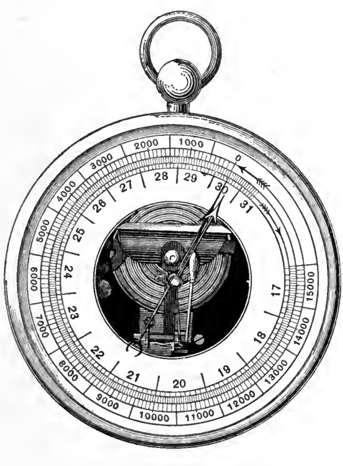


FIG. 16.

16. Aneroid Barometer. — The aneroid barometer (Fig. 16) consists of a round flat box from which most of the

* Davis, Elementary Meteorology. Ginn & Co.

air has been pumped. It is made of metal so thin that any increase in the pressure of the air on the exterior can slightly press down its upper surface. When the pressure of the air is decreased, the top of the box rises again. The amount of motion of the top of the box is so slight that it cannot be readily noticed. It is, however, made evident by a little mechanism attached to the top of the box, which causes the end of a small pointer to move a considerable distance around the face of a dial covering the box, even when the motion of the thin top of the box is but slight. The dial resembles very much the face of a watch, but is supplied with two sets of figures. The inner one of these indicates the height in inches at which a mercurial barometer would stand under similar conditions of air-pressure. The outer set, often placed on a movable ring, is used to indicate approximately in feet the level of the observer above the sea (Fig. 16).

If there has been a change of weather between the observations at two localities, the barometer cannot be used to determine with any reasonable degree of accuracy their difference in elevation.

17. Variation of Density of Air with Altitude.—If the opening of a pocket bicycle-pump is closed by means of a finger and the plunger is then pushed inward, the air within the pump is forced by the plunger into a smaller space, or, is *compressed.* The greater the pressure exerted by the plunger upon the air, the smaller is the *volume,* or the amount of space occupied. The air which has been crowded together into smaller space is said to be more *dense.* The density of air within any space varies with the amount of air crowded into that space.

The upper part of the atmosphere rests upon that which is below. It possesses weight, and, because of

this weight, it pushes down upon and compresses the air beneath it. On this account the lower parts of the atmosphere are more compressed than the upper parts.

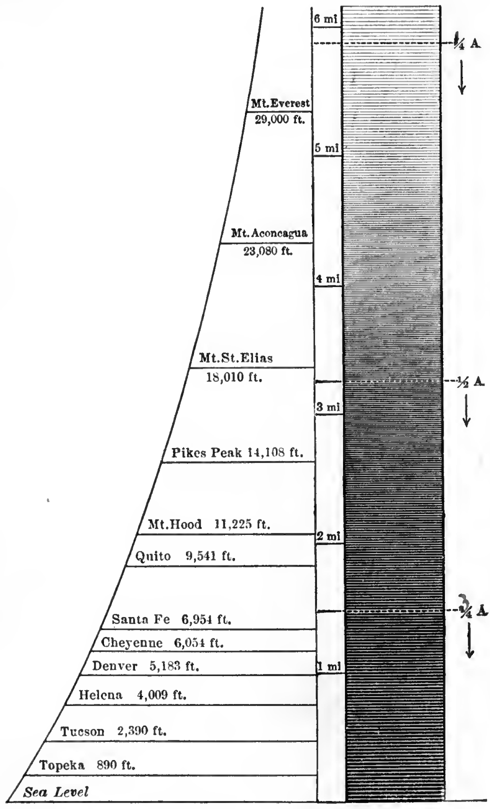


FIG. 17.

Consequently, the greater quantity of the air is found near the surface of the earth. At an elevation of $1\frac{1}{2}$ miles above the earth, the density of the air is less than $\frac{3}{4}$ of the density at the level of the sea, at $3\frac{1}{4}$ miles it is

about $\frac{1}{2}$ of the density at sea level, and at 6 miles it is less than $\frac{1}{4}$ as great (Fig. 17). Half of the entire atmosphere is found crowded together within $3\frac{1}{2}$ miles of the sea level, and about $\frac{3}{4}$ of the atmosphere is found within 6 miles of sea level. It is evident that 100 miles above the earth's surface the air must be exceedingly thin or rare.

18. Total Pressure Exerted by Atmosphere on Human Body.—The pressure of the air at sea level is about 14.7 pounds per square inch (§ 12). Every square inch of the surface of the human body is subjected to a pressure of 14.7 pounds. Since the total surface of the body is equal to hundreds of square inches, the total atmospheric pressure upon the body amounts to a number of tons. It has been calculated to exceed 15 tons, or 30,000 pounds, for an average-sized person. If the body were not saturated with blood, lymph, and other liquids, it could not withstand this enormous pressure. But our bodies are constructed so as to be most healthy when under this pressure. Without it we feel uncomfortable. On the tops of high mountains, where the pressure is much reduced, breathing becomes more rapid and more laborious, the pulse beats more quickly, painful headaches and vomiting often result, and any physical exercise causes great fatigue.

Fish living at the bottom of the sea are subjected to enormous pressure. Nevertheless, fish adapted to those great depths live there comfortably. In the fish here figured (Fig. 18) the eyes are very large in proportion to the size of the fish, and the lower half of the body is covered with phosphorescent spots. This enables the fish to see at great depths. Were the great pressure to which they are accustomed diminished to any very considerable extent, they would suffer great pain, possibly death.

Alexander Agassiz says, "In fish brought up from deep water, the swimming-bladder often protrudes from the mouth, the eyes are forced out of their sockets, the scales

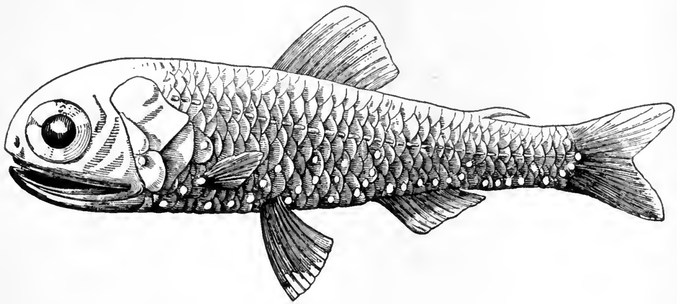


FIG. 18.

have fallen off, and they present a most disreputable appearance."

Just as deep-sea fish need the greater pressures of the deeper water, so we need the greater pressures of the air found at lower altitudes on the earth's surface.

19. Balancing of Liquids in U-tubes. — Pour mercury into a U-tube of uniform bore with arms at least 20 inches long, until the mercury rises to a height of about 4 inches in one arm. What is the height of the mercury in the other arm? Pour additional mercury into the same arm of the tube until the mercury on this side rises to a height of about 6 inches. The mercury rises to the same height in the other arm, and the two columns of mercury exactly balance each other.

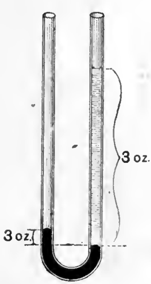


FIG. 19.

Now pour 3 ounces of water on top of the mercury in the right arm (Fig. 19). What effect is produced upon the level of the mercury in the other arm?

Although the liquids in the two arms do not rise to the same level, the water and the mercury remaining in the right arm of the tube together balance the total quantity of mercury which is now present in the left arm. The mercury remaining in the right arm balances only that part of the mercury in the other arm which does not rise above the level of the mercury in the right arm. That part of the mercury in the left arm which rises above this level, is balanced by the water which has been poured into the right arm. If the pressure exerted by the water is 3 ounces, then the pressure exerted by that part of the mercury in the left arm which is balanced by the water is also 3 ounces.

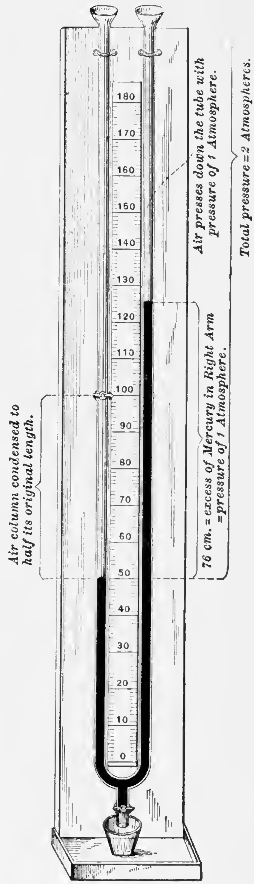


FIG. 20.

20. Boyle's Law: Apparatus. — Pressure affects the volume of gases. To illustrate the relation between pressure and volume, the following apparatus has been devised (Fig. 20). A long glass tube of uniform bore is bent at the middle, so as to resemble a very much elongated letter U. The tube is mounted vertically, with the open ends upward. The parallel arms should have a length of 180 centimeters, or about 71 inches. A glass stop-cock is inserted 100 centimeters, or

about 40 inches, above the base of the left arm, in order to close this arm whenever necessary. A short tube with a second stop-cock is attached to the base of the U-tube for convenience in emptying the apparatus at the close of the experiment.

Close the stop-cock at the base of the tube and open the stop-cock in the left arm. Pour in mercury until it rises slightly above the curved part at the base of the two arms of the tube. The mercury rises to the same level on both sides. Since the air in the two arms is subjected to the same atmospheric pressure, the density of the air in both is the same. Close the stop-cock in the left arm. This neither increases nor diminishes either the density or the pressure of the air in that arm. It merely confines the air already present. Since the pressure of the confined air remains the same, the surface of the mercury remains at the same level in the two arms. In other words, while the total atmosphere is pressing with a certain force upon the mercury at the base of the right arm, the small quantity of air confined in the left arm is pressing with equal force on the mercury there.

21. Boyle's Law: Experiment.—Determine the height of the mercury in the barometer at the time of the experiment.

Pour mercury into the right arm of the apparatus used in the preceding experiment until the difference between the levels of the mercury in the two arms is equal to the height of mercury in the barometer (Fig. 20). The mercury now present in the left arm balances only an equal height of the mercury in the right arm. But the mercury in the right arm above this level is balanced by the increased pressure now exerted by the air confined in the left arm. This increased pressure is caused by

the fact that the air confined in the left arm has been condensed into a smaller space and therefore presses back with greater force. Since that part of the mercury in the right arm which rises above the level of the mercury in the left has the same height as the mercury held up in the barometer, it exerts the same relative pressure as the atmosphere at the time of the experiment.

At the beginning of the experiment the pressure of the air confined in the left arm balanced the pressure of the total atmosphere pressing down the open arm. The air confined in the left arm therefore also exerted a pressure of one atmosphere. Now the pressure of the air in the closed arm balances both the pressure of the air in the open arm and the excess of mercury in that arm, a total pressure of two atmospheres. Therefore, when the difference between the levels of the mercury in the two arms is equal to the height of the mercury in the barometer, the pressure of the air confined in the left arm is equal to two atmospheres.

Observe that the air in the left arm occupies now only one-half of its original volume. In other words, its present density is double its original density. This demonstrates that:

When air is reduced to one-half of its original volume, or, when its density is doubled, it exerts double its original pressure.

If mercury should be added to the right arm until the excess of mercury in that arm is equal to twice the height of the mercury in the barometer, then a total of three atmospheres of pressure would be exerted upon the balanced part of mercury in the lower part of the U-tube. The air confined in the left arm in that case, however, would occupy only one-third of its original volume,

in other words would possess three times its original density and exert three times its original pressure.

From a series of such experiments the following rules can be derived:

The pressure of a gas varies inversely as its volume and directly as its density.

The volume of a gas varies inversely as the pressure which it exerts, or which is exerted upon it.

The density of a gas varies directly as the pressure it exerts, or the pressure is exerted upon it.

These rules are often expressed in a condensed form known as Boyle's Law.

What is the meaning of the mathematical expressions "varies inversely" and "varies directly"?

22. Valves.—One of the common forms of valve consists of a piece of leather which is caused, by its weight, to rest on or against an opening. One edge of this piece of leather is attached, to prevent it from shifting its position. When the pressures on both face and back of the valve are equal, the weight of the valve keeps it closed. If the pressure against the face of the valve (the side in contact with the opening) is, in any manner, made greater than the weight of the valve plus whatever pressure may be exerted upon its back, the valve is pushed open (Fig. 21, A). When the weight of the valve plus the pressure on its back is greater than the pressure on the face, the valve is pushed against the opening (Fig. 21, B). In the latter case, when the differ-

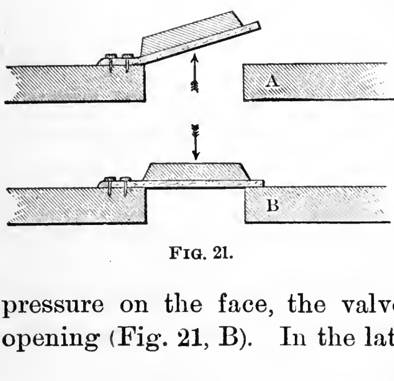


Fig. 21.

ence in pressures is considerable, the valve is closed with sufficient force to prevent any gas or liquid from passing through the opening.

The pressures acting upon valves are usually caused by gases or liquids, usually air or water. In the case of a large valve, such as is used in the various kinds of pumps, the valve is often stiffened by a piece of wood or iron fastened to its back.

23. Piston.—A *piston* is a round disk or plate which, although it can be moved back and forth in a cylinder, fits so tightly against the inner wall of the cylinder that no air can pass between the piston and the wall. The rod by means of which the piston is moved is called the *piston-rod*. In some pumps an opening passes vertically through the piston, at or near its centre, and this is covered by an outward-opening valve in order to permit the passage of air in an outward direction only (Fig. 22, A, B). When the piston is not provided with such an opening, all passage of air from one side of the piston to the other is prevented (Fig. 22, C, D). In this case the outward-opening valve is placed within a tube leading out laterally from the lower part of the cylinder.

In both kinds of pump there is an inward-opening valve which closes the opening at the base of the cylinder. Where it is desired to force the piston down so far that it will come in direct contact with the base as in the air-pump, this inward-opening valve is placed in a little depression formed at the upper end of the opening passing through the base.

24. Pumps.—Before either form of pump is set in operation, the same atmospheric pressure is found at all points within and without the pump. When the piston is forced downward, the air enclosed within the lower part of the

cylinder below the piston, is compressed. The air which has been compressed exerts a greater pressure than the atmosphere without. In consequence, the inward-opening valve, wherever placed, is forced shut, and the outward-opening valve is forced open (Fig. 22, A, C). Air continues to escape through the opened valve, until the pressure of the air remaining in the cylinder below the piston is reduced so nearly to the pressure of the atmosphere without that it no longer holds up the valve. Then the valve drops on account of its own weight.

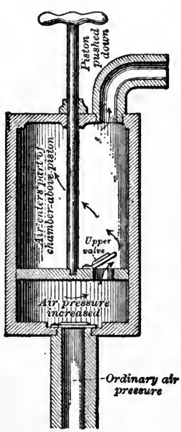


Fig. 22 A.

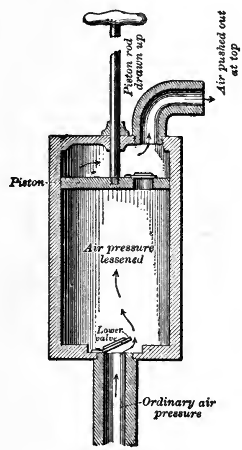


Fig. 22 B.

When the piston is raised, the air remaining in the lower part of the cylinder is given room for expansion. As it expands its density becomes less, and it then exerts less pressure than the atmosphere without. In consequence, the outward-opening valve is held shut and the inward-opening valve is forced open (Fig. 22, B, D). The air from the outside then enters the cylinder. When the pressure of the air within the cylinder has increased to

such an extent that the pressure of the outside atmosphere is no longer sufficient to hold open the inward-opening valve, the valve drops.

When the piston is lowered the second time, the air just admitted to the lower part of the cylinder is compressed in its turn, and is forced, in the manner already described, through the outward-opening valve. The operation of the piston, therefore, causes an inflow of air through the inward-opening valve at each rise of the

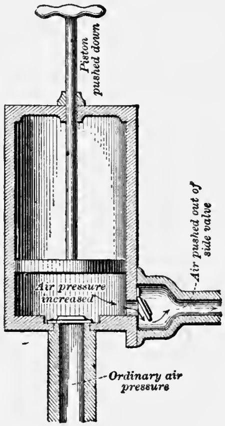


Fig. 22 C.

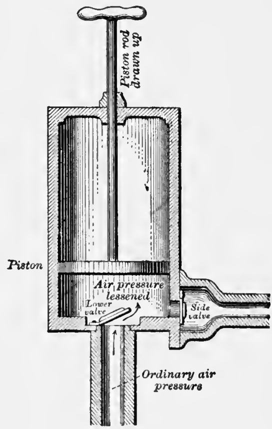


Fig. 22 D.

piston, followed by an outflow through the outward-opening valve at each descent. In consequence, air passes in an intermittent stream through the inward-opening valve into the lower part of the cylinder, and then out through the outward-opening valve. In order to pump air out of any vessel it is necessary to connect the vessel with the inward-opening valve. In order to pump air into any vessel the vessel must be connected with the outward-opening valve.

25. Air-Pump: Use of Pump-Plate and Bell-jar.—In a pump used for pumping out air (Fig. 23) the opening beneath the valve at the base of the cylinder is connected by means of a tube with a second opening which passes up through the centre of a flat circular plate of iron or brass. This plate is called the pump-plate. The inner wall of the opening through the plate is supplied with

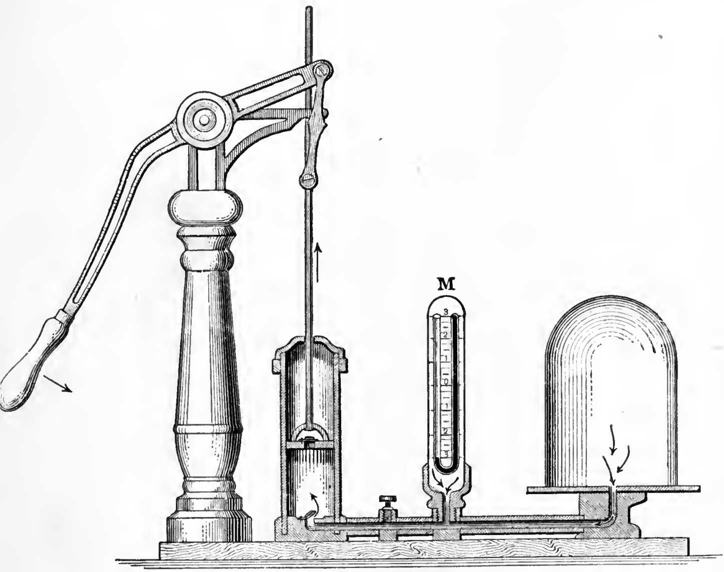


FIG. 23.

a spiral screw thread, so that it is possible to screw vessels, air-tight, into the top of this plate. Any hollow vessel screwed into the pump-plate is then connected to the pump by means of the tube already mentioned. For this reason the base of the hollow sphere used to determine the weight of air (§ 2), and the lower end of the brass tube of the vacuum fountain vessel (§ 7) are screwed into

the opening in the pump-plate, when it is desired to remove the air.

For the purpose of exhibiting experiments demanding the removal of part or all of the air surrounding the apparatus, tall, cylindrical glass vessels, called bell-jars or receivers, are placed on the pump-plate. In order to prevent air from entering between the pump-plate and the base of the bell-jar, the lower edges of the jar are ground perfectly flat, so that they may rest evenly upon the plate. The entrance of the air may be prevented still more effectually by coating the base of the bell-jar with a thin layer of tallow, and then forcing the jar against the pump-plate with a slightly twisting motion. Softer fats and oils are serviceable but are not as effective.

As soon as any considerable portion of the air within the bell-jar has been removed, the pressure of the air within is diminished so much that the exterior atmosphere presses the jar against the plate with sufficient force to make it difficult, or, in the case of a large bell-jar, practically impossible to remove the jar from the plate. Under these conditions very little air can enter between the base of the bell-jar and the pump-plate.

When it is desired to remove the jar, air must be admitted in some manner to the interior of the bell-jar. This is provided for in some air-pumps by placing, on one side of the tube connected with the base of the pump-plate, a valve which can be opened whenever necessary. In the case of the air-pump illustrated by the figure air may be admitted between the pump and the manometer at an opening usually closed by means of a screw plug.

26. Action of Air-Pump.—At the beginning, the pressures of the air in the receiver, and of the air in the cylinder of the pump, both below and above the piston,

are the same. In a good air-pump, the piston, when forced to its lowest position, fits so snugly against the base, that but a very slight quantity of air can remain in the lower part of the cylinder. When the piston is raised, this slight quantity of air expands so many hundred times, in occupying the enormously increased space now present below the piston, that its pressure becomes almost nothing. At the moment the piston begins to ascend, the pressure of the exterior atmosphere closes more tightly the outward-opening valve in the piston, while some of the air within the bell-jar and within the connecting tube forces its way through the inward-opening valve into the lower part of the cylinder (Fig. 23). When the piston is forced downward, the air which has entered the lower part of the cylinder beneath the piston is compressed ; this enables it to close the inward-opening valve connecting with the passage to the bell-jar and to force its way out through the outward-opening valve in the piston.

Each upward and downward movement of the piston is a repetition of these processes. Each upward stroke permits more air to flow from the bell-jar into the lower part of the pump-cylinder, and each downward stroke forces most of this air to pass to the space above the piston. In consequence, the quantity of air remaining in the bell-jar steadily diminishes. Since, in a good air-pump, the slight quantity of air remaining in the lower part of the cylinder exerts almost no pressure when the piston is raised, the air in the bell-jar will continue to force its way into the pump as long as it is able to overcome the weight of the lower valve at the base of the cylinder. The degree of exhaustion which can be secured by a good air-pump is, therefore, determined to a large extent by the lightness of the lower valve.

the pipe beneath the lower valve, which is located at the bottom of the pump-barrel.

In a pump which has not been used for any considerable time, the piston is likely to become dry and to shrink sufficiently to permit air to pass between it and the walls of the pump-barrel. A small quantity of water poured into the barrel will remedy this defect temporarily. Why?

29. Height to Which Water may be Raised by the Lifting-Pump.—In the vacuum fountain experiment (§ 7), the pressure of the air within the vacuum fountain vessel was less than the pressure of the air on the surface of the water in the jar into which the open end of the tube at the base of the vessel was dipped. In consequence of the greater pressure of the outer air, the water in the jar was forced up into the vessel. In a similar manner, after pumping has reduced the quantity of air in the pipe below the pump-barrel, and has thus diminished the pressure of the air which remains in the pipe, the pressure of the outer atmosphere on the water in the well is able to push a part of the water up the pipe.

The distance the water is forced up the pipe depends upon the degree of exhaustion of the air in the pipe, and upon the amount of pressure exerted by the outer atmosphere at the time of pumping. It has been shown that under the most favorable circumstances, the atmosphere at sea level can hold up only about 34 feet of water (§ 8). This is, therefore, the extreme height to which the atmosphere can push water up a pump-stock. A rise of 34 feet demands a perfect vacuum in the pipe up which the water is forced. This state of exhaustion is never reached by a water-pump. In practice, the pump-maker does not expect the water to rise much higher than 28 feet. He,

therefore chooses a pump-barrel of such length that the valve in the bucket is not more than 28 feet from the surface of the water in the well.

In order to pump water from a deep well it is necessary to construct a pump-barrel of such length that it will extend from the pump-spout down to within 28 feet of the surface of the water in the well. The bucket is fastened to a rod of such length that when the bucket is on its downward stroke it descends to within one or two inches of the bottom of the pump-barrel. In case the pump-barrel is 100 feet long, a vertical height of nearly 100 feet of water is lifted within the pump-barrel at every upward stroke of the pump-rod, when once the water has begun to flow out at the spout. Every down-stroke of the pump-handle causes an up-stroke of the pump-rod and bucket.

30. Detailed Description of Action of Lifting-Pump.— When the lifting-pump is first set in operation it acts like an air-pump in removing the air from the pipe below the pump-barrel. When the piston, or bucket, is raised for the first time, the air in the lower part of the pump-barrel expands so as to fill the extra space below the bucket. This reduces the pressure of the air in the barrel below that of the air in the pipe. The air in the pipe is able, therefore, to push up the lower valve, and a part of the air in the pipe enters the lower part of the barrel. Owing to the diminution in the quantity of air in the pipe situated below the lower valve, there is also a reduction of the pressure of the air remaining in the pipe, so that the atmosphere presses more strongly upon the surface of the water in the well than the air within the pipe does upon the water immediately beneath it. This unequal pressure of air causes water to rise in the pipe, until the downward

pressure of the air remaining in the pipe together with the downward pressure of the water which has risen within the pipe balances the pressure of the atmosphere on the water in the well.

Each successive stroke of the bucket permits more air to escape from the pipe into the barrel. By this means the pressure of the air remaining within the pipe is reduced more and more, and this permits the pressure of the outside air on the water in the well to force more water into the pipe, so that it will rise to higher and higher levels within the pipe. After each stroke the water rises in the pipe until the downward pressure of the air and of the water which has risen within the pipe balances the pressure of the atmosphere on the water in the well.

Finally, if the valve in the bucket is not too far above the surface of the water in the well, some of the water in the pipe is forced above the lower valve of the pump. This leaves a small quantity of air between the bucket and the surface of the water which has now risen above the lower valve. At the next descent of the bucket, in addition to this last remnant of air, a part of the water in the barrel is also forced above the valve in the bucket. At the next ascent of the bucket no air remains beneath it in the pump-barrel. Consequently, the water which is forced up the pipe by the outside air follows immediately after the bucket and fills the space below it.

At the next descent of the bucket the water at the bottom of the pump-barrel cannot escape downward, but is forced through the valve in the bucket into that part of the barrel which is above. With each following upward stroke of the bucket more and more water enters the lower part of the pump-barrel, and with each downward

stroke more water is forced into that part of the pump-barrel which is above the bucket (Fig. 24, A), until finally a part of the water runs out of the spout near the top.

The pump is now started. Each downward stroke of the bucket causes some of the water which has last entered the lower part of the pump-barrel to pass up through the valve in the bucket, and each upward stroke lifts the water which is above the bucket sufficiently to allow the upper part of the water thus lifted above the level of the spout to run out (Fig. 24, B).

31. The Force-Pump.—The force-pump, in its construction and action, is quite similar to the lifting-pump. The outward-opening valve, however, is not attached to the piston, but is placed somewhere within the tube which leads laterally from the base of the barrel and forms an outlet for the water which it contains. The piston does not lift water as in the lifting-pump, but, during its downward stroke, forces the water out of the base of the barrel, through the tube (Fig. 25).

Neither form of pump produces a steady stream. The flow of water is greater during the upstroke of the piston in the lifting-pump, and during the down-stroke in the force-pump.

The flow of water from a force-pump, however, may be made much more steady by employing an air-chamber. This air-chamber consists of a hollow vessel, open only at the base. It is usually provided with two openings, one for the entrance of water coming from the pump, the other for the exit of water into a second tube. In this case the name delivery tube may be applied to the tube through which the water escapes from the air-chamber. In the case of a fire-engine a nozzle is attached to the farther end of the delivery tube where the

water escapes. The nozzle of the delivery tube is made so narrow that the pump can force water into the air-chamber more readily than the water can escape through the nozzle. This causes the water to rise in the air-chamber, and to compress the air, which the water confines to the upper part of the chamber. As the water rises in the air-chamber, the air imprisoned in its upper portion is more and more compressed. The compressed air exerts a counter-pressure upon the water in the air-chamber, and forces it out through the nozzle at the end of the delivery tube. This action of the imprisoned air continues to force out water through the nozzle at the end of the delivery tube even while the piston is rising in the pump-barrel. The valve in the delivery tube is at the base of the air-chamber and prevents the return of the water to the pump during the upstroke of the piston.

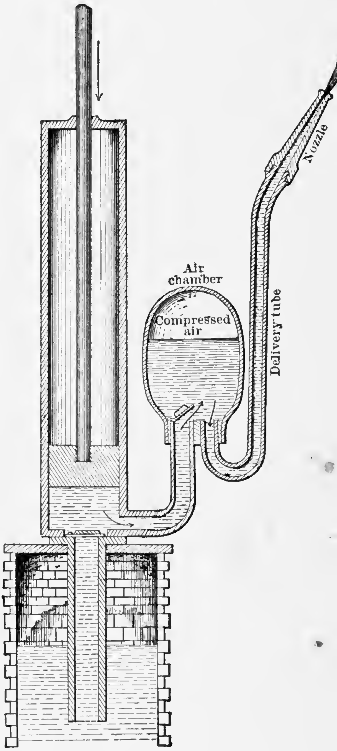


FIG. 25.

If the pump is worked with sufficient rapidity the piston begins to descend before the air in the air-chamber can force out much of the water in the lower part of the chamber. The more rapid the action of the pump, the shorter is the time during which the pressure of the air in the chamber may decrease, and the more steady will be the outflow of the water at the end of the

nozzle. Moreover, the more rapid the action of the pump, the greater is the amount of water forced up into the air-chamber, the greater is the degree of compression suffered by the air, and the swifter is the stream of water forced out through the nozzle.

32. Stop-cocks.—A stop-cock is a contrivance by means of which the passage through a tube can be either partly or entirely opened and closed at will. The essential part of a stop-cock consists in a slightly tapering stopper or plug, commonly known as the spigot, inserted air-tight into a hole which passes at right angles through the walls of the tube. The plug is fastened in such a manner, that, while it cannot be withdrawn, it can be readily turned. A hole is drilled crosswise through the plug at such a point that, when the plug is turned in one position, this hole is in line with the tube and thus forms a passage continuous with the tube. When, however, the plug is turned either to the right or to the left, the hole through the plug is turned away from the passage through the tube, thereby preventing all movement of liquid or gas farther than the walls of the plug.

Sometimes a stop-cock is used not merely to open or to close the passage through a tube, but also, when occasion requires, to connect the interior of the tube with the outside. This can be accomplished by drilling a hole transversely through the plug or spigot, as in the previous case, and then drilling another hole at a right angle to the first, extending from the surface on one side of the plug as far as, but not beyond, the other hole which passes through the centre of the plug. In other words, the two holes in the plug join so as to form the letter **T**.

When the hole which passes entirely through the plug is in line with the tube, the second hole, which joins it

at right angles, points toward one of the lateral walls of the tube. An opening is drilled through this wall of the tube so that in one position of the plug the first hole through the plug is in line with the tube and the second hole is in line with the opening in the wall (Fig. 26, a). In this position a fluid may pass through the plug out into the open air, or in the inverse direction. This is the position of some plugs used to admit air to the tube connecting the air-pump with the bell-jar, when it is desired to permit air to return into a bell-jar from which air has previously been removed. If the plug is turned half way around, the passage through the tube is unobstructed, but there is no connection with the side opening (Fig. 26, b). At certain intermediate positions of the stopcock the passage through the tube is entirely obstructed (Fig. 26, c).

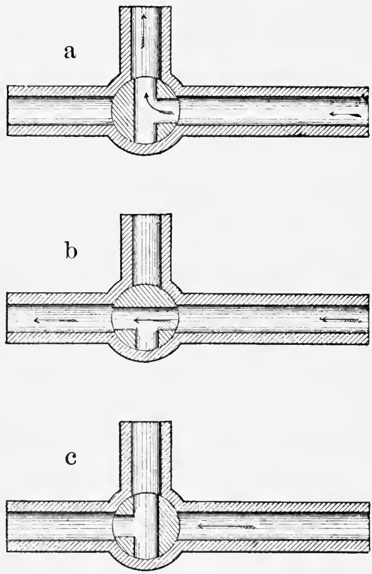


FIG. 26.

33. Manometer.—A manometer is an instrument for determining the degree of exhaustion of the air from a bell-jar or other vessel. It consists essentially of a closed cylindrical vessel containing a narrow U-shaped tube closed at one end. The closed arm is filled with mercury, great care being taken to exclude all air from this arm.

The mercury is prevented from running over into the open arm by the pressure of the air (Fig. 23). As soon as the pressure of the air in the manometer is reduced by pumping so much that it is no longer sufficient to sustain the weight of all the mercury in the closed arm, the mercury in this arm falls and a part runs up into the open side.

The proportion of air still remaining may be determined by noticing the height to which the upper surface of the mercury in the closed arm rises above that in the open arm. If the mercury in the barometer, at the time of the use of the manometer, rises to a height of 30 inches and the difference in the level of the mercury in the two arms of the manometer tube is 3 inches, only $\frac{1}{10}$ as much pressure is exerted by the air in the manometer as by the atmosphere outside. This indicates that $\frac{9}{10}$ of the air has been pumped out of the manometer. When all of the air has been removed, the mercury assumes the same level on both sides of the manometer tube. As soon as the air is admitted to the vessel, the mercury is pushed back into the closed arm of the tube. In order to have the space under the bell-jar entirely free for experimental purposes, the manometer is usually attached to the tube connecting the air-pump with the bell-jar. The degree of exhaustion of the air in the bell-jar is accompanied by an equal degree of exhaustion in the manometer and is determined as soon as the degree of exhaustion in the manometer is known.

Since the manometer is used chiefly to determine the amount of air remaining in a vessel after almost all of the air has been removed, it is not necessary to use a U-tube more than 8 or 10 inches long. In that case the mercury will not fall until the degree of exhaustion of

air in the manometer is so great that the air can no longer support the 8 or 10 inches of mercury present in the closed arm at the beginning of the experiment.

34. The Tension of Liquid Films.—Dip a pipe into soapsuds and produce a soap-bubble at the bowl of the pipe. Notice that it is necessary to blow with some force to enlarge it. When the mouth is removed from the stem of the pipe, the film contracts and the bubble becomes smaller.

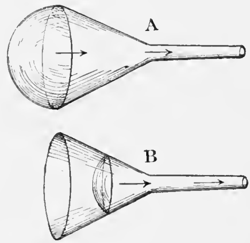


Fig. 27.

Wet a funnel thoroughly with water. Form a film across the larger end of the funnel by dipping it into soapsuds. Blow into the funnel so as to expand the film (Fig. 27, A) and then remove the mouth. The film contracts and on this account travels inward towards the narrow end of the funnel (Fig. 27, B).

Make a wire ring about 4 inches in diameter, and twist the ends of the wire so as to form a handle. Fasten the ends of a short piece of thread to points on the wire ring about 3 inches apart, so that the thread will hang down loosely for a short distance. Dip the ring into soapsuds. A film forms across the entire ring and supports the thread (Fig. 28, A). By means of a pencil the thread can be moved from side to side without destroying the film. Break the film in the narrower of the two spaces between the ring and the thread. All of the film within this space at once disappears. The film within the larger space contracts and stretches the thread, so that the latter forms a regular curve (Fig. 28, B).

Dip the ring a second time into the soapsuds and pierce the film in the broader space between the ring and

the thread. That part of the film within the narrower space draws the thread against the wire ring. Catch hold of the thread and pull it toward the central part of the ring. The film is re-formed. Let go. The thread is pulled back as though the film consisted of stretched rubber.

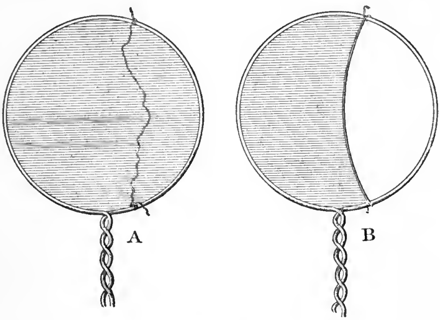


FIG. 28.

It is evident in all of these experiments that thin films of liquids act more or less like stretched membranes.

The experiments will be more likely to succeed if a small quantity of glycerine is added to the soapsuds.

35. Surface Tension of Liquids.—Fill a test-tube with water. Keep the edges of the test-tube dry and add water drop by drop. The level of the water will rise considerably above the edges of the tube without overflowing. It behaves as though it were covered by a thin film attached to the edges of the glass.

Dip a narrow glass tube into water and then take it out. A small part of the water which rose into the tube still remains in the tube. The lower part of the water sags below the level of the glass and behaves very much as if it were held up by a sac or thin film attached to the margin of the glass.

Hold a small needle horizontally within a short distance of the water in a vessel. Drop it. It floats on the surface, but the part of the surface nearest the needle is now depressed and forms a little trough at the bottom of

which rests the needle (Fig. 29). Press on the needle and see how quickly, after it has once broken through the surface, it falls to the bottom of the vessel. If the needle is removed without breaking through the surface, the surface flattens again. The surface of the water in the vessel behaves as though it consisted of a stretched film which is depressed by the weight of the needle but which springs back as soon as the needle is removed.

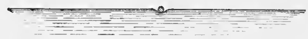


FIG. 29.

This imaginary surface film appears to have considerable strength and can be subjected to considerable tension before breaking. If, for instance, an aluminum medal about as large as a silver dollar be carefully placed in a horizontal position on the surface of the water, the medal will float, although it forms a depression in the surface of the water.

The individual hairs of a camel's-hair brush when dry stand slightly apart, producing a somewhat bushy appearance. Dip the brush into water. The bushy appearance remains while the brush is in the water. The mere presence of water is not sufficient to alter its appearance. Take the brush out of the water. The surface of the water adhering to the brush at once contracts and draws the individual hairs together again, giving the brush a pointed appearance. The surface of a liquid acts as if it were covered by a film always tending to contract.

The surface of a small quantity of mercury contracts until it can contract no longer. It then forms a spherical mass and may be called a drop of mercury. A drop of water is merely a small quantity of water whose surface has contracted so much that a spherical form is assumed. Melted lead poured through a sieve at the

top of a high tower appears at the bottom as rounded shot.

On account of phenomena similar to those here described, it is convenient to refer to the surface of a liquid as if it were covered by a surface film, and, since this film appears to be stretched or in a state of tension, the expression *surface tension* is used in the discussion of many phenomena. An explanation of the cause of the phenomena known as surface tension requires the use of the molecular theory. After this theory has been taken up, it is well to return to a consideration of these phenomena. Briefly stated, the molecules within the liquid are equally attracted in all directions by surrounding molecules, and hence do not give any evidence of tension. However, those at the surface are attracted only downward and laterally, not upward. Hence the surface molecules act as though they formed a laterally stretched membrane held tight against the main body of water.

36. Glassworking.—To cut a glass tube, lay it on the table, and, by means of a single forward stroke with a three-cornered file, make a short but deep scratch across the tube. Placing the thumbs directly behind the scratch, gently push with the thumbs against the tube, at the same time pull with the hands, and the tube will break at the point desired (Fig. 30). If the tube is large, wrap it in cloth before trying to break it.

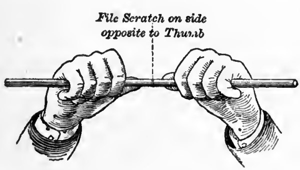


FIG. 30.

Rotate the end of the tube slowly in the flame of a Bunsen burner until the flame turns yellow. The glass is softened by the heat and its surface is melted. In consequence of the shrinking of the surface film of the glass the

sharp edges at the end of the tube arc ıounded. If the end of the tube is held a longer time i the flame, the contraction of the surface film begins to diminish the size of the opening, and this may be continued until an opening of any desired size is obtained, or until the opening entirely closes. When the tube has melted shut for a distance back from the end exceeding the thickness of the walls of the tube, blow quickly but evenly into the open end. The surface film resists the expansion of the glass in all directions so evenly that the glass takes the form of a small bulb or sphere. If the melted glass at the end of the tube is sufficiently soft, a sphere may be blown as large as a soap-bubble.

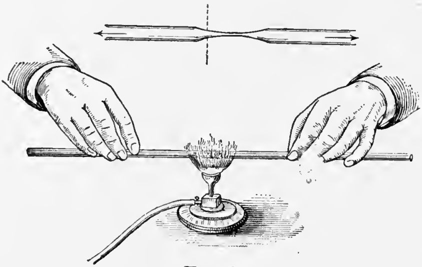


FIG. 31.

To bend a glass tube heat evenly a length of two inches, moving the tube to right and left and rotating it in the luminous part of an ordinary gas flame (Fig. 31). As soon as the glass becomes soft enough, bend it a little at every point along the heated portion, but avoid any sharp bend (Fig. 32).

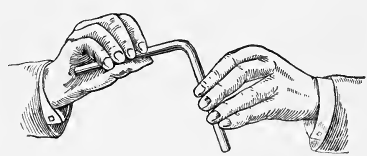


FIG. 32.

If a length of two inches is heated long enough to be soft, and the ends of the tube are gently drawn apart, the glass will stretch like taffy, and the diameter of the tube will become narrower at this point. If considerably heated and rapidly drawn apart, the

stretched part of the tube may become as fine as a coarse hair.

In order to secure a glass handle for a platinum wire (§ 229), heat a small part of a glass tube and stretch it moderately so that the diameter of the heated part is reduced about one half (Fig. 31). If the heated part is moderately stretched, the walls of the tube remain thicker. Cut this part with a file as above described. Insert the platinum wire in this end of the glass tube and place it in the flame of the Bunsen burner (Fig. 33). The glass will close in around the wire and hold it in position.

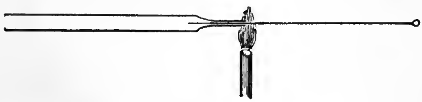


FIG. 33.

In order to secure a platinum tip at the end of the delivery tube for experiments with burning hydrogen (§ 149), roll a piece of platinum foil around that end of a file which enters the handle. Withdraw the hollow conical tube thus formed and slip it into a glass tube (which has been stretched and cut in the manner described above) so that the pointed end of the platinum tube projects. Heat the narrowed end of the glass tube until it closes in around the larger end of the platinum tube.

The opening of a glass tube may be enlarged while it is heated by spreading it with the narrow end of a file.

37. Attraction of Water for Water.—The force with which the different parts of a mass of water hold together can be shown by the following experiment.

Secure a circular piece of ordinary window-glass, 4 inches in diameter. By means of sealing-wax, attach three strings at equidistant points near the margin of the disk. Tie the ends together and fasten them to the

hook beneath a delicate spring balance (8-ounce, graduated to $\frac{1}{4}$-ounce intervals) in such a manner that the disk will hang perfectly horizontal. Determine the weight of the disk. Place a vessel of water beneath the glass disk, and lower the balance until the glass disk comes in contact with the water.

Slowly lift the balance. The disk gradually rises and pulls a small part of the water above the general level of the water in the vessel (Fig. 34). As the balance is lifted higher and higher, the index of the balance is pulled lower and lower, showing that the water in the vessel is pulling down the disk. At the same time the amount of water pulled by the disk above the general water level increases. Finally the disk flies upward. It seems to have been pulled away from the water in the vessel. On examining the lower surface of the disk, however, a small quantity of water is seen clinging to its lower surface. This shows that the separation did not occur between the disk and the water, but that the film of water still clinging to the disk was pulled away from the main body of water remaining in the vessel. The film of water does not remain spread evenly over the surface of the disk, but soon collects together in little drops, (§ 35).

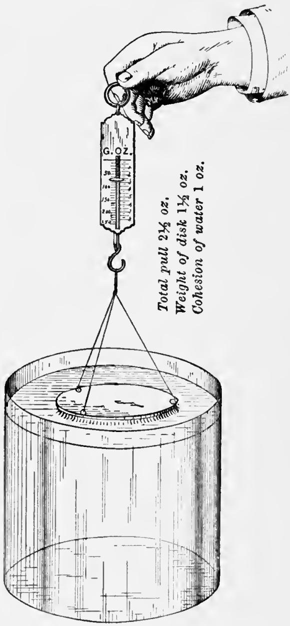


FIG. 34.

The balance indicates what force is required to pull the water attached to the disk away from the water in the vessel.

38. Adhesion and Cohesion.—It will be noticed that a film of water separates from the water remaining in the vessel and clings to the glass plate. This indicates that the attraction of water for glass is greater than the attraction of water for water. The attraction between unlike substances, for instance between water and glass, is called *adhesion*. The attraction between masses of the same kind of substances, for example the attraction of the water film for the water in the vessel, is called *cohesion*. The adhesion between water and glass is greater than the cohesion between water and water.

39. Water Drawn Up on Vertical Walls of Glass.—The attraction of water for glass can be shown by other phenomena. A *phenomenon* is not necessarily an unusual or striking occurrence. Indeed, most phenomena are quite ordinary or commonplace. Any change of position, form, color, or chemical composition which takes place, in fact, anything which happens, whether caused by man or by natural forces, is often called a phenomenon in physics.

Examine the water which has been placed in a tumbler. The surface of the water is flat except at the edges, where it curves upward against the sides of the glass.

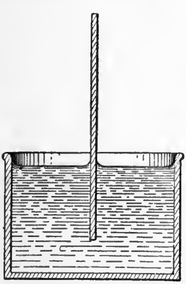


FIG. 35.

Dip the lower part of a plate of glass vertically into water. Notice how high the water rises on the sides of the glass (Fig. 35). Now dip two plates into water so that they form a very small angle with one another, the two vertical edges on one side being in contact. The water rises to a greater height between the plates than it does on their outer surface, especially where the distance between the plates is very small (Fig. 36).

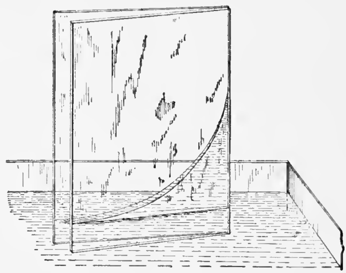


FIG. 36.

In all of these experiments the attraction between glass and water causes the water to creep up along the sides of the glass. In the experiment last described, the water rises to the greatest height where the two plates of glass come in contact with each other, for at this point both plates act at the same time, and from within a very short distance, upon the same particles of water.

40. Capillary Tubes.—Take glass tubes of different sizes, the internal diameter or bore of the largest tube not exceeding $\frac{1}{8}$ of an inch. Arrange them in a series, beginning with the tube of the largest bore. Fasten the tubes vertically in small openings bored through a short piece of wood. The lower ends of the tubes should be at the same level. Dip the tubes vertically into water. Notice in the various tubes the relation between the size of the bore and the height to which the water rises, and the degree and direction of curvature of the upper surface of the water within the tube (§ 43).

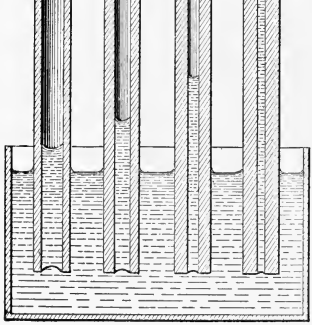


FIG. 37.

Water rises to the greatest height in the tube having the smallest bore (Fig. 37). The rule is that *The vertical rise of the water varies inversely as the*

diameter of the tube. In a tube having one-half the diameter water will rise to twice the height. This principle is shown in the most striking manner by tubes whose internal diameter is exceedingly small. Tubes of glass have been constructed whose internal diameter does not exceed that of a hair, and, since tubes of this size were often used in experiments of this nature, the action of liquids in narrow tubes is often referred to as the action of liquids in hair-like or capillary tubes, or, as *capillarity.* The ascent of liquids in fine capillary tubes is well illustrated in the ascent of oil or alcohol along the wick of a lamp. On approaching the flame, the oil or alcohol vaporizes or turns into gas. Where this gas comes in contact with the air it burns, when once lighted. Close to the wick the gas is given off too rapidly to become mingled with air and here there is no flame (Fig. 38).

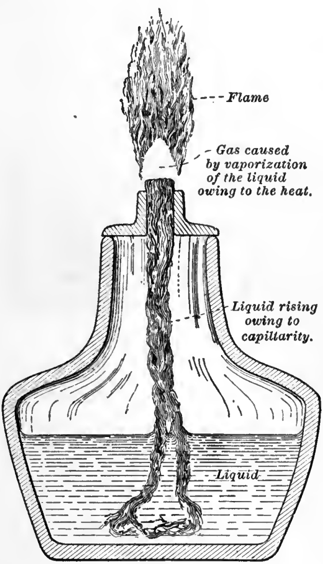


FIG. 38.

Dip tubes of different diameters into mercury (Fig. 39), and notice the relationship existing between the size of the bore, the amount of depression of the mercury in the tubes below the general level of the mercury in the vessel, and the degree and direction of curvature of the surface (§ 43). What is the difference in the direction of the curvature of the surface of the water and of the mercury in these tubes?

41. Concave and Convex Surfaces.—Regularly curved surfaces are distinguished either as *concave* or *convex.* If an observer, on looking at a regularly curved surface, finds that the edges curve toward him, so that from his point of view the surface seems to be hollowed out, the surface is said to be concave (Fig. 40). When, however, the surface from the centre to the margin curves away from him, so as to have the appearance of a part of a solid globe or sphere, the surface is said to be convex. When viewed from the side, regularly curved surfaces are said to be concave when the edges curve upward and convex when the edges are curved downward.

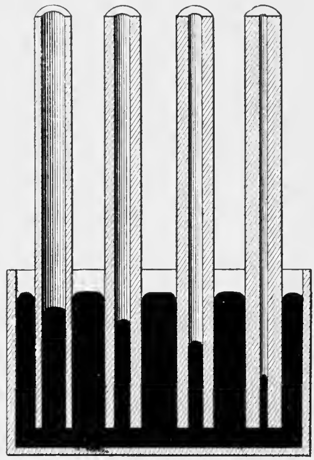


FIG. 39.

Which of the surfaces in the experiments above are concave and which are convex?

42. Comparison of Cohesion of Water and of Cohesion of Mercury with the Adhesion of These Substances to Glass.—It has been explained that water creeps up on the sides of a piece of glass because the attraction of water for water is less than the attraction of water for glass. This accounts for the concave surface of the water in the glass tubes.

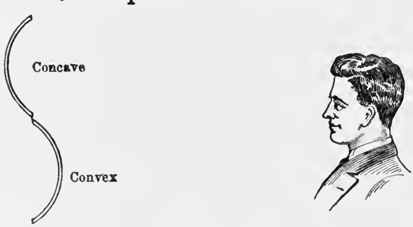


FIG. 40.

When a small glass plate is dipped in mercury, the mercury seems to shrink from contact with the glass (Fig. 41). The attraction of mercury for mercury is greater than the attraction of mercury for glass. In consequence, the main body of the mercury within the vessel draws that part of the mercury which is in contact with the glass towards itself so effectively, that, where the upper surface of the mercury meets the glass, the mercury is drawn away from the glass and in consequence its margin curves strongly downward. This has the effect of making the upper surface of the mercury convex when placed within a narrow glass tube.

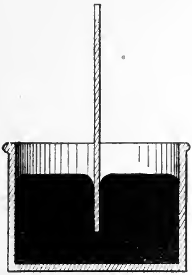


FIG. 41.

If the attraction of mercury for glass were as great as the attraction of mercury for mercury, the surface would be perfectly horizontal, even at its actual contact with the glass.

43. Capillary Action Due to Surface Tension.—The surface of a liquid acts as if it consisted of a stretched film which seeks to contract or shrink (§ 35).

If a plate of glass previously moistened is dipped in water, the film of water adhering to the glass meets the film forming the surface of the water at a right angle. But these films tend to contract and so the corner at which they meet is rounded off, and the water is said to rise along the glass. The contraction of the film continues until the weight of the liquid raised by the film above the general level of the water in the vessel balances the force with which the film is able to contract.

Moisten a glass tube of small bore so that the interior is covered by a film of water. Dip the tube into a vessel

of water. The film of water lining the interior of the tube meets the film forming the surface of the water within the tube at first at a right angle, but the contraction of these films causes the angle of contact to become rounded. Consequently the water rises along the walls of the tube. As the contraction of the films continues, the water rises also at the central portion of the tube. Any further contraction of the films causes the water to rise both along the walls and in the middle regions of the tube.

When the tube has not been previously moistened, a thin film of water creeps up the walls of the tube owing to the strong attraction of glass for water (§ 38). The contraction of this film where it comes in contact with the water in the tube causes the same phenomena as those already described.

When a narrow glass tube is dipped into mercury, the mercury does not form a film on the glass. Consequently any contraction of the surface of the mercury within the tube is not accompanied by a rise of mercury along the walls. On the contrary, the edges of the surface of the mercury, where they come in contact with the glass, are drawn away from the glass, since the attraction of mercury for mercury is greater than the attraction of mercury for glass. This gives the surface of the mercury within the tube a convex curvature, and further contraction of this surface must be accompanied by a depression of the mercury within the tube below the general level of the mercury in the vessel. This depression of the mercury in the tube continues until the force with which the surface film of the mercury within the tube contracts is balanced by the upward pressure caused by that part of the mercury in the vessel which rises above the level

of the mercury which has been depressed within the tube.

44. Siphon.—Dip a narrow glass tube under water. Place the finger over the upper end, and, holding it in a vertical position, remove the tube. The water is held in by the pressure of the air against the surface film of the water at the lower end of the tube. Remove the finger. The water drops out. Explain.

Take a narrow glass tube about 15 inches long, with an internal diameter not exceeding $\frac{1}{4}$-inch, and bend it at 5 inches from each end, so as to form a rectangular U-shaped tube. Fill the tube with water. Be careful to permit no air-bubbles to remain. Cover one of the openings with a finger and invert the tube, keeping the two openings at the same level. The water is held in at the open end of the tube by the pressure of the air against the surface-film of water. Now remove the finger without changing the level of the tube. The water is held in at both ends by the pressure of the air (Fig. 42, A). The

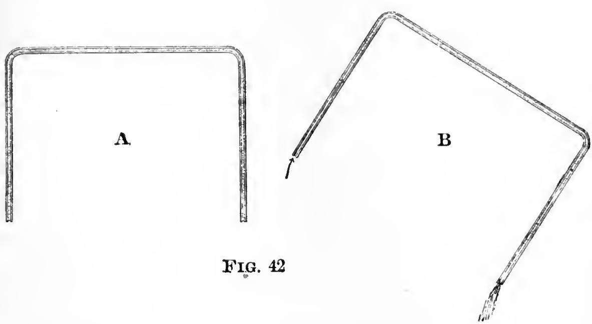


FIG. 42

success of this experiment depends upon the ends of this tube being held at precisely the same level. Any slight change in the relative level of the openings at once

causes the water to escape from the lower opening (Fig. 42, B).

Bend a glass tube, about 36 inches long, into a rectangular U-shaped form, so that one arm will be 5 inches and the other 25 inches long. Fill with water in such a way that no air-bubbles remain, and, placing a finger over one of the open ends, invert the tube. The pressure of the air prevents the escape of the water. Now remove the finger and the water flows out rapidly. Try the experiment again, closing the other arm of the tube. From which arm does the water escape in both cases? A tube of this form will serve very well as a siphon.

45. Principle of the Siphon.—The fact that the water flows from the shorter out through the longer arm, does not mean that the pressure of the air is greater at the end of the shorter than at the end of the longer arm. In fact, the pressure at the end of the shorter arm is slightly less than the pressure at the end of the other arm; but so slightly less that the two pressures are practically equal.

While the pressures of the air at the ends of the two arms are practically equal to one another, that part of the air pressure which is available for moving the water from either opening through the tube to the other opening, is not the same at the lower end of the short arm as at the lower end of the long arm of the tube. A part of the pressure of the air at the end of the shorter arm is used in supporting the water in this arm, and only the remainder of the pressure can be used to push the water toward the other end of the tube. In the same manner, a part of the air pressure at the end of the longer arm is used to support the water in that arm. But this column of water is longer than that in the other arm, and hence a smaller part of the air pressure remains available for

pushing the water from this side over toward the shorter arm. Hence, in spite of the tendency of the air to hold up the water in both arms, the water is pushed from the side of the short arm toward the long one.

The greater the difference in the length of the two arms, the greater will be the inequality of the weights of water to be supported, the greater also will be the difference in the amount of air pressure available for pushing the water from one side of the tube toward the other, and the greater will be the rapidity of the flow of water out of the longer arm.

46. Use of Siphon.—If, before removing the finger from either end of the siphon, the end of the short arm be dipped under the surface of the water in a jar, and the finger be then removed, the water will flow from the longer arm as before (Fig. 43). As the water flows out of the longer arm it tends to leave behind it an empty space or vacuum. The pressure of the air on the water in the jar then forces more water up through the shorter arm, keeps both arms full of water, and thus makes possible a constant flow of water through the siphon.

FIG. 43.

In the same manner it is possible to remove liquids from barrels and from carboys which are too heavy to be easily tilted, but which permit the insertion of a siphon at the top. Siphons are often improvised from rubber tubes for the purpose of emptying barrels of cider. Glass siphons are especially constructed for the purpose of removing acids from large glass bottles called carboys.

The length of any arm of a siphon can be determined by measuring the vertical distance from the open end of the tube to the highest point in the siphon (Fig. 44). When the lower part of the arm is dipped into water, the length of the arm is found by measuring the vertical distance from the water surface to the highest point in the siphon.

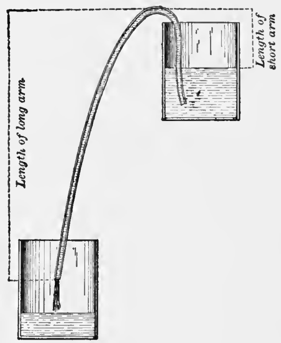


FIG. 44.

47. Downward Pressure of Liquids on the Base of Vessels Having Vertical Sides.—Fasten a glass cylinder, whose lower end has been ground flat, in a vertical position over a vessel. Attach a string to the hook at the centre of a round brass plate whose upper surface is perfectly flat, and whose diameter slightly exceeds the diameter of the cylinder. Draw the loose end of the string up through the cylinder and fasten it to a second hook attached to the lower side of one of the pans of a balance. At first arrange the apparatus so as to allow neither the string nor the brass plate to touch the cylinder. Place weights on the other pan of the balance until the beam is horizontal. Then move the balance until the string is in the centre of the cylinder and raise the balance beam until the brass plate barely touches the base of the glass cylinder. If the upper surface of the brass plate is perfectly horizontal, it will now fit neatly against the base of the cylinder. Pour water into the cylinder. The water at once escapes at the base.

Place an additional weight of 2 ounces on the other pan of the balance. The brass plate is now held up against the base of the cylinder by a force of 2 ounces.

Therefore, it now requires a force greater than 2 ounces to pull or push the plate away from the cylinder. Pour a small quantity of water gently into the cylinder. It remains in the cylinder. Add more water. When a certain level is reached the water (Fig. 45) begins to run out in drops between the base of the cylinder and the plate. If

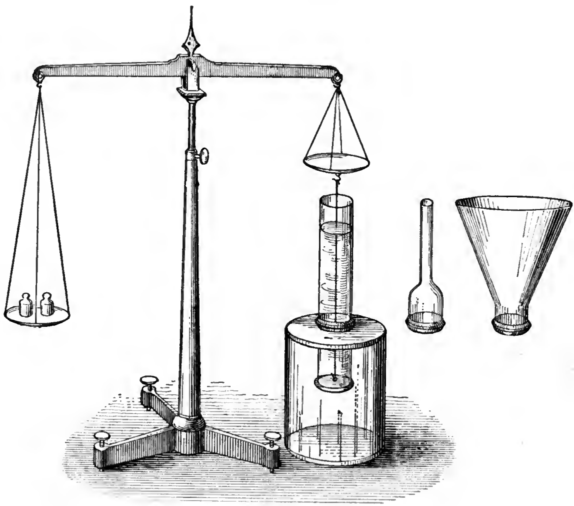


FIG. 45.

the water is poured into the cylinder too rapidly, it runs out at the bottom in a steady stream.

Repeat the experiment. In each case water begins to flow out when it has attained a certain level within the cylinder. Measure the depth of the water in the cylinder at the moment when the water begins to escape. Then let this water flow into a small vessel and determine its weight. It will weigh 2 ounces. This indicates that the moment before the water began to escape, the weight in

the pan and the downward pressure of the water in the cylinder exactly balanced. Any further addition of water to the cylinder causes the escape of water at its base. This is in accordance with the statement made in the earlier part of the paragraph, that a force of more than 2 ounces is required to push the brass plate away from the cylinder.

Now add 2 ounces to the weights already present on the other pan. Again pour water into the cylinder, and determine the depth of the water in the cylinder when the water begins to escape at the base. This depth is found to be twice that observed in the preceding part of the experiment. Determine the weight of the water in the cylinder as before.

Repeat the experiment, using greater weights.

The observations so far made are numerous enough to justify the following conclusions. *The downward pressure of water on the base of a cylinder varies with the depth of the water.* Since the cylinder was placed in a vertical position, all the weight of the water rests upon the base. Therefore, *in the case of a vessel with a vertical wall, the downward pressure of a liquid on the base is equal to the weight of the liquid within the vessel.*

The downward pressure exerted by a liquid on the base of a vessel varies also with the density of the liquid. To show this repeat the experiment, using first a saturated solution of salt water and then a lighter liquid like coal oil. With cylinders of different diameter it may be shown that *the downward pressure exerted by a liquid varies with the size or area of the surface which forms the base.*

48. Downward Pressure of Liquids on the Base of Vessels Whose Sides are Not Vertical or are Partly Vertical.—Instead of a glass cylinder take a vessel having the form of

a large glass funnel. The opening at the lower and narrower end of the funnel should be exactly equal in size to the opening at the base of the cylinder used in the preceding experiment. The base of the funnel must be perfectly flat. Fasten the funnel in a vertical position and arrange the brass plate, the balance, and the weights, as at the beginning of the preceding experiment. In the apparatus figured, a different device is used which serves the same purpose as that described (Fig. 45).

Place, in succession, weights of 2, 4, 6, or more ounces upon the free pan of the balance. After each addition to the weights, pour water into the funnel and record the height at which the surface of the water stands above the brass plate when the water begins to escape at the base. Compare these results with the results in the preceding experiment. It is found that the same depth of water is required to produce the same pressure on the brass plate at the base of the funnel as at the base of the cylinder. This is true, notwithstanding the fact that, in order to secure the same depth of water in the funnel as in the cylinder, a much greater volume of water is required. From this we may draw the conclusion that in the case of vessels with vertical or with spreading sides, *the pressure of a liquid on the base varies with the depth of the water, but is independent of the volume of water used.*

Replace the funnel with a vessel having a form similar to that of an argand lamp chimney (Fig. 45)—narrow throughout the greater part of its length, but widening suddenly a short distance above its base. The base should be ground flat and its diameter should equal the diameter of the cylinder used in the first of this series of experiments. Adjust the brass plate, balance, and weights. Follow the same methods and record the facts

observed as before. Compare the records with those previously obtained for the cylinder and funnel.

It is found that the same depth of water is required in the chimney as in the funnel and in the cylinder to produce the same pressure on the brass plate at the base. This is true, notwithstanding the fact that the same depth of water in the case of the chimney requires a considerably smaller volume than in the case of either the funnel or the cylinder. Similar results are obtained by using vessels very irregular in form but having an equal area at the base. From this we draw the conclusion, *that the pressure of water upon any horizontal surface varies with the depth of the water above the surface, but is independent of the volume of water used.* On the same surface a small volume of water produces as great a pressure as an enormously greater quantity of water, provided that the depth be the same. To produce this effect in a striking manner, the smaller quantity of water must be placed in a vessel having the same diameter at the base, but a diameter at the top much smaller than in the vessel used for the larger quantity of water.

49. The Upward Pressure of a Liquid on Any Area Is Equal to its Downward Pressure on the Same Area at the Same Distance beneath the Surface.—Take three sticks, each of them one inch square, but respectively 4, 6, and 8 inches in length. Bore a hole lengthwise in each stick to within about a quarter of an inch of the opposite end. Put in shot as ballast. Place two or three round pieces of pasteboard over the shot and ram the shot down tight. Close the openings with cork. Cut off the cork even with the surface of the wood. Let the total weight of the sticks, including the shot, pasteboard, and cork, be 2, 3, and 4 ounces respectively. Place the three sticks under

a bell-jar and pump out the air in the jar. A great portion of the air enclosed in the fibres of the wood is removed at the same time. As soon as possible after pumping out the air, boil the sticks for a short time in hot, melted paraffine, so that the surface of the wood shall be soaked with paraffine. This will prevent the sticks from becoming water-logged.

Place the three sticks in a tall glass jar containing water (Fig. 46). Notice the depth to which each sinks into the water. The base of the 2-ounce stick is about $3\frac{1}{2}$ inches below, the base of the 3-ounce stick is about $5\frac{1}{4}$ inches below, and the base of the 4-ounce stick is about 7 inches below the surface of the water. The sticks press downward on the water upon which they rest with a force of 2, 3, and 4 ounces respectively. Nevertheless, they do not sink to the bottom of the vessel. The water upon which the sticks rest is in each case pressing upward with the same force with which the sticks are pressing downward; otherwise the sticks would either rise or sink. The upward pressure of water on a surface one inch square is, therefore, 2 ounces, 3 ounces, and 4 ounces at levels approximately $3\frac{1}{2}$, $5\frac{1}{4}$, and 7 inches below the surface.

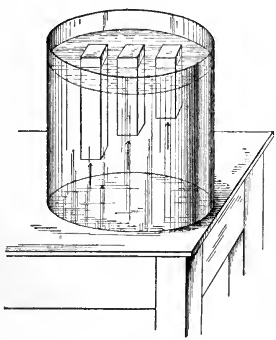


Fig. 46.

The same result will be obtained no matter whether the sticks be placed in a shallow or in a deep vessel. The upward pressure of water on any area immersed in it depends, therefore, not upon the depth of the water beneath the area pressed upon, but upon the depth of

the water above this area; in other words, upon the distance of this area beneath the surface of the water.

The downward pressure of water on any area is equal to the weight of a column of the water having vertical walls and having an equal area as a base (§ 47). This downward pressure may be determined mathematically by finding the area pressed upon, in square inches, then multiplying this by the distance of the area below the surface of the water expressed in inches, and finally multiplying the product by the weight of a cubic inch of water.

A cubic inch of water weighs .577+ ounce (§ 57). Calculate the downward pressures of water on areas one inch square, at depths of $3\frac{1}{2}$, $5\frac{1}{4}$, and 7 inches. The downward pressures are approximately 2, 3, and 4 ounces respectively.

Compare the downward pressures, obtained by calculation, with the upward pressures as determined in the present experiment. It will be found that on the same areas placed at the same depths beneath the surface of the liquid, the upward and downward pressures are equal. This fact is of the greatest importance in explaining the apparent loss in weight of bodies immersed in liquids (§ 51).

50. Loss of Weight of a Body Immersed in a Liquid.— Attach a stone by means of a long string to a spring balance, and find its weight. Hold the balance over a jar of water, lower the stone into the water, and determine its weight again (Fig. 47). Notice that the stone apparently loses in weight when immersed in water. Place your hand beneath the body of a person swimming in water. Notice how easily you can support his weight though using only a finger or two (§ 52).

51. Cause of This Apparent Loss in Weight.—Place a rectangular block of wood or of any other substance in a vertical position beneath the surface of the water in a glass jar (Fig. 48). The only direction in which water can press upon the top of the block is downward; the only direction in which it can press against the sides is lateral; and the only direction in which it can press against the base is upward. The various pressures against the sides balance each other. This is shown by the fact that the block is not pushed toward any side, but remains wherever placed. If the pressures are unequal, the block is pushed in a direction from the stronger force toward the weaker force. The downward and upward pressures cannot balance one another, since the upward pressure which is exerted against the bottom of the block at a lower depth is greater than the downward pressure which is exerted on the top of the block at a less depth beneath the surface of the water.

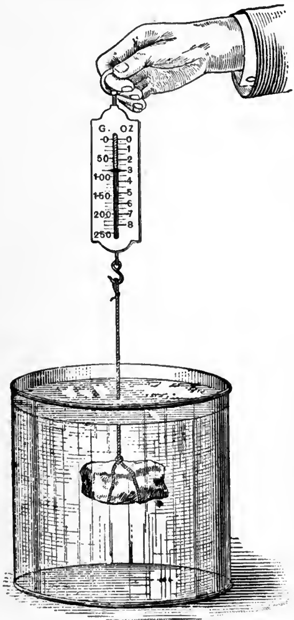


FIG. 47.

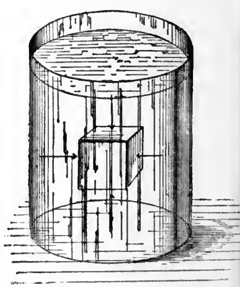


FIG. 48.

If the upper surface of the block have an area of 2 square inches, and if this top be 5 inches below the surface of the water, the downward pressure of

the water on the top of the block is about 5.75 ounces (§ 47). If the base be of equal area, and if it be 8 inches below the surface of the water, the upward pressure of the water on the base will be about 9.25 ounces (§ 49). In this case the upward pressure will be 3.5 ounces greater than the downward pressure. If, therefore, the block weighs less than 3.5 ounces, it will rise and float; if it weighs exactly 3.5 ounces, it will remain in the position in which it was placed; and if it weighs more than 3.5 ounces, it will sink.

Calculate the weight of the volume of water pushed aside by the block. Its volume is $2 \times 3 = 6$ cubic inches. Its weight is $6 \times .577+ = 3.5$ ounces approximately. Therefore, in order that a body may sink, it must weigh more than an equal volume of water.

Even though a body sinks in water, and thus shows that it is heavier than the water, it nevertheless apparently loses in weight. This is necessarily true since the upward pressure against the base of the block immersed is always greater than the downward pressure on the top. An examination of the numbers in the preceding paragraph shows that a body immersed in a liquid apparently loses in weight an amount equal to the weight of a quantity of the liquid whose volume is equal to the volume of the body immersed.

In ordinary language we say that a body immersed in a liquid loses in weight because of the buoyancy of the liquid. Buoyancy is not a separate force. It is simply the effect produced by the inequality between the downward and upward pressures exerted by a liquid upon any immersed body.

52. Buoyancy of Gases.—Loss in weight occurs also when a body is immersed in a gas. The loss is usually

small, because there is but a small difference between the downward and the upward pressures of gases on areas at nearly the same level. The loss in weight can easily be detected by means of a delicate balance. A body weighed in air weighs less than the same body weighed in a vacuum. A boy weighing 125 pounds in a vacuum will weigh about $2\frac{1}{2}$ ounces less when weighed in air. In estimating the weight of the boy, the loss in weight due to immersion in air is never considered.

The loss of weight in water is much more likely to be appreciated, especially by boys who are in the habit of swimming. A boy will lose by far the greater part of his weight if he is weighed in water. If his lungs be kept well inflated with air, his weight in water will be so small that a slight exertion on his part will enable him to float. Some persons can float, apparently without exertion, while lying in the water, back downward, with their lungs well inflated.

53. Pascal's Law.—Select a bottle with a neck of such an even bore, that a cork of the same diameter can be moved up and down in the neck like a piston in a cylinder. Fill the bottle with water. Insert the cork. Since the cork fits tightly, no water can escape. Suppose that the neck of the bottle is of such a diameter that, when the bottle is filled, the surface of the water within the neck has an area of one square inch. Then the cork inserted in the neck rests upon a water surface of one square inch. Suppose the cork to be pressed down with a force of one pound upon the square inch of water surface with which it comes in contact in the neck. Then imagine a hole with an area of one square inch to be cut in the side of the bottle. It is evident that, disregarding the pressure due to the weight of the water, a pressure

of one pound is required to keep the water from running out of this hole. If the number of holes be increased, a pressure of one pound will be required on each hole to prevent the escape of the water (Fig. 49). In other words, every square inch of surface within the bottle will sustain a pressure of one pound, in addition to the pressure which it already sustains due to the weight of the water alone.

Fig. 49.

The principle here involved may be stated as a general rule known as Pascal's Law.

Fluids enclosed in a vessel, when subjected to pressure, transmit this pressure undiminished in all directions so that every surface in the interior of the vessel, equal in area to the surface upon which the pressure is exerted, receives a pressure equal to that applied.

In case a wide and a narrow vessel are connected by a tube at the bottom and almost filled with water, the level of the water in the two vessels is the same. If a movable piston be placed on the surface of the water in each vessel, and a weight be placed on the smaller piston, this weight will balance a weight placed on the larger piston as many times greater as the area of the water surface of the wider vessel exceeds that of the narrower one.

It is difficult to make clear the reasons for the facts here presented. It may be best for the present to omit any explanation. In the future, when the student knows more about molecules and the laws governing their ac-

tion, the subject can be studied with more profit. The practical application of this law is, however, of considerable importance.

54. Hydrostatic Pressure Used to Lift Weights.—Take a short brass cylinder, having a diameter of nearly six inches, with an opening through its base into which is inserted the end of a short brass tube, and with a brass plate which works up and down in the

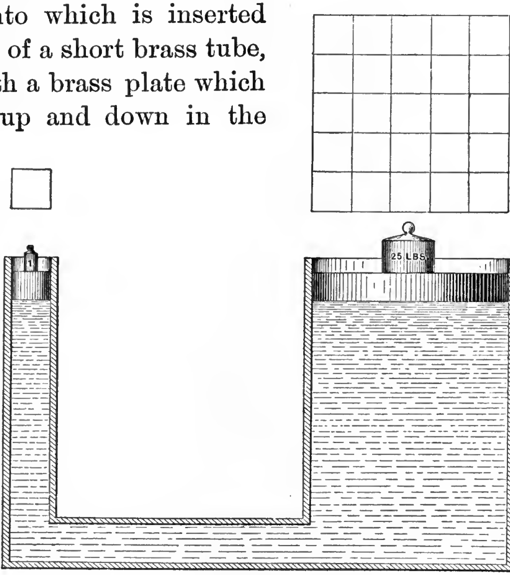


FIG. 50.

cylinder like a piston. This is the same apparatus as that described in paragraph 12, but inverted.

Carry the apparatus into the hall and place it near the staircase. Thrust the plate down against the bottom of the cylinder. Place upon it a block of wood high enough to project slightly above the margin of the cylinder. On top of the block put a board and ask one of the pupils to stand upon it. Slip one end of a short piece

of rubber tubing over the brass tube at the base of the cylinder and into the other end insert a stop-cock. Attach to the other end of the stop-cock about thirty feet of stout rubber tubing filled with water, and into the farther end of the tubing insert a funnel.

Close the stop-cock. Pour sufficient water into the funnel to nearly fill it. Carry this end of the tube to the top of the stairway. Open the stop-cock (Fig. 51). The water escapes into the lower part of the cylinder and pushes upward against the base of the brass plate. The pupil is lifted up very slowly but steadily. If the funnel be kept full of water, the pupil will continue to be lifted until the plate reaches the top of the cylinder.

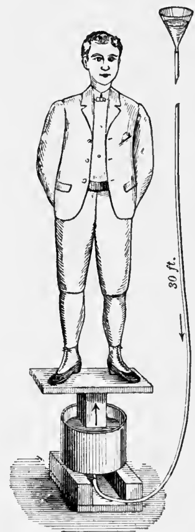


FIG. 51.

The pressure of the water on the area at the bottom of the rubber tubing is quite small. This is because the area exposed here is quite small. The area of the brass plate is several hundred times larger than the area at the base of the rubber tube. It sustains, therefore, several hundred times the pressure sustained by the area at the base of this tube. Although the downward pressure at the base of the narrow tube is small, the upward pressure against the broad brass plate is sufficient to lift the pupil.

55. Hydraulic Press.—In the same manner, in the hydraulic press, the pressure exerted upon a small surface of water by means of the piston of a sort of force-pump, is transmitted to every equal area on the base of a very large piston (Fig. 52). A small pressure by means of the

small piston causes a great total pressure against the much larger base of the large piston.

The principle of the hydraulic press is used for many purposes: to lift bridges, elevators, and even ordinary barbers' chairs. The newest forms of hoisting-jacks, cider-presses, and oil-presses make use of the same principle.

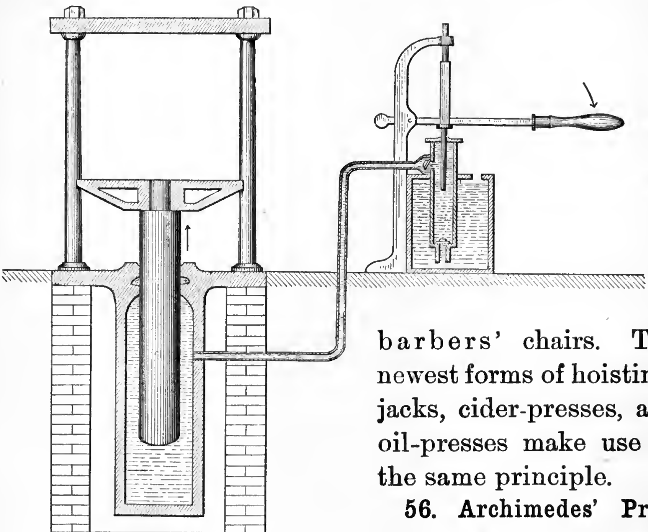


FIG. 52.

56. Archimedes' Principle. — An overflow-can consists of a brass vessel about 3.5 inches in diameter and 6 inches high, supplied near the rim with a short, nearly horizontal tube which serves as a spout. Pour water into the can until it runs out through the spout. After the water has ceased flowing from the can, place beneath the spout a small brass bucket whose weight has been previously determined by means of a spring balance.

Attach a rock to the same balance by means of a thread. Weigh the rock in air, then lower it slowly into the can and weigh it again in the water. Determine the apparent loss in the weight of the rock due to the buoyant

effect of the water. If the water caught in the bucket was forced out of the overflow-can only in consequence of displacement by the rock (Fig. 53) and not owing to any jerking motion during the weighing of the rock in the water, then determine the combined weight of the bucket and of the water which has run over into it from the can.

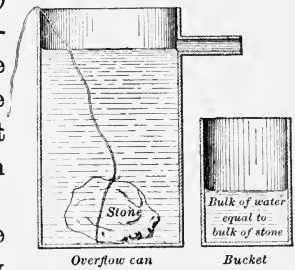


Fig. 53.

Next find the weight of the water displaced by the stone, by subtracting the weight of the bucket alone from the weight of the bucket and the water. Compare the loss in weight of the rock due to buoyancy with the weight of the water displaced by the rock. They are the same.

From this we learn, that *a body immersed in a liquid apparently loses in weight an amount equal to the weight of the liquid displaced.*

This statement of fact is usually known as *Archimedes' Principle.*

57. Specific Gravity.—The *specific gravity* of a substance is a number which shows how many times heavier that substance is than an equal volume of another substance taken as a standard. The standard for solids and liquids is distilled water at a temperature of 4 degrees Centigrade, or 39.2 degrees Fahrenheit. A reading of 4 degrees on the Centigrade thermometer indicates the same temperature as that indicated by the reading of 39.2 degrees on the Fahrenheit thermometer. At this temperature water has its maximum density; in other words, at this temperature a given weight of water occupies less space and therefore is more dense than at any other temperature.

In determining the specific gravity of gases, hydrogen subjected to a barometric pressure of 30 inches (§ 14) is usually taken as the standard. Sometimes air is taken as the standard.

Iron has a specific gravity of 7.8. This means that any piece of pure iron is 7.8 times as heavy as an equal bulk of water. If, for instance, it is desired to find the weight of one cubic foot of iron, it is sufficient to multiply the weight of one cubic foot of water by 7.8. The weight of one cubic foot of water has been found by careful weighing to be 62.42 pounds (§ 49). A cubic foot of iron, therefore, weighs 487.88 pounds.

58. Specific Gravity of Solids Heavier than Water.—How is it possible to determine the fact that the specific gravity of iron is 7.8? Take any piece of pure iron. Weigh it in air. Determine the weight of an equal volume of water. Divide the weight of the iron in air by the weight of the equal volume of water. The quotient is the specific gravity of iron. To determine the weight of an equal volume of water, weigh the water which escapes into the bucket when the piece of iron is lowered into an overflow-can full of water.

It is possible to secure the weight of an equal volume of water without using the overflow-can and the bucket. From Archimedes' Principle we know that the apparent loss in weight of any rock, immersed in water, is equal to the weight of a mass of water equal in volume to the volume of the rock. It is, therefore, sufficient to determine the apparent loss in weight of the rock in the water, in order to know the weight of an equal volume of water. For instance, if the rock weighs 5 ounces in air and apparently 3 ounces in water, the so-called loss in weight is 2 ounces. Hence the weight of a mass of water

equal in volume to the volume of the rock is also 2 ounces.

If the rock weighs 5 ounces in air and an equal bulk of water weighs 2 ounces, the rock must weigh 2.5 times as much as an equal bulk of water.

The greater weight of rock as compared with the weight of water is believed to be due to the fact that there is actually more material in a cubic inch of rock than in a cubic inch of water. Rock is believed to be more compact, or more dense. In accordance with this idea, the particular kind of rock here used is said to be 2.5 times as dense as water. The number which specifies how the density of any substance compares with the density of water is called the *Specific Density* of that substance. Therefore, the specific density of the stone in the preceding example is 2.5. In other words, its density is 2.5 as great as the density of water.

Since the weight of a body is proportional to the amount of material in it, the specific gravity of a substance is the same as its specific density. For this reason these two terms are often used interchangeably.

The method used in determining the specific gravity of any substance depends upon its weight, solubility, chemical action when exposed to air or immersed in water, and other properties. A few additional methods are described in the following paragraphs. The underlying principle in all of these methods is the comparison of the weights of equal bulks of these substances and of water.

59. Specific Gravity of Solids Lighter than Water.— Attach a small block of wood to a balance and weigh it. To the block fasten a stone heavy enough to drag the block beneath the surface of water. Hold the spring balance over a jar of water and lower it sufficiently to

permit the entire stone to dip beneath the surface of the water, while all of the block remains in the air (Fig. 54, A). Determine the combined weight of block and stone in this position. Lower the balance still farther, until both block and stone are under the surface of the water (Fig. 54, B). Ascertain the weight of both in this position also. The loss

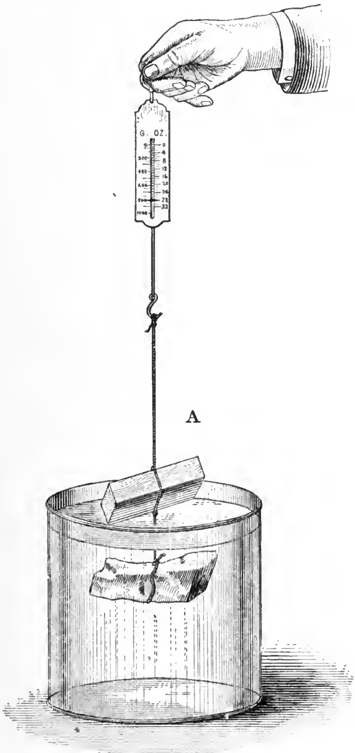


FIG. 54.

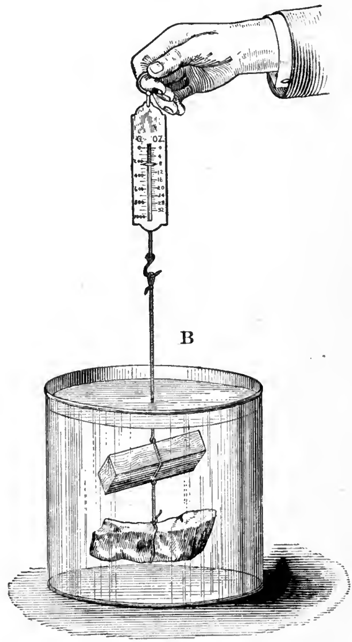


FIG. 54.

in weight of the combination is due to the buoyant effect of the water upon the block of wood. This loss in weight, according to Archimedes' Principle, is equal to the weight of a quantity of water whose volume is equal to the volume of the block.

If the combination, while the block is in air and the stone is in water, weighs 28 ounces, and the combination when the block is also under water, weighs 8 ounces, then the weight of a volume of water equal to the volume of the block is 20 ounces. If the weight of the block alone is 14 ounces, the wood is .7 times as heavy, bulk for bulk, as water, or its density is only .7 times as great as that of water. In other words, the specific gravity or the specific density of the kind of wood investigated is .7.

60. Specific Gravity of Liquids.—First method. Find the weight of an empty bottle. Weigh the bottle when filled with water, and afterwards weigh it again when filled with the liquid whose specific gravity is to be determined. In this manner the weights of equal volumes of water and of the liquid are obtained. To find how many times heavier the liquid is than an equal volume of water, divide the weight of the liquid by the weight of the water. The quotient obtained is the specific gravity of the liquid.

Second method. Weigh a solid in air, then in water, and then in the liquid. The loss in weight of the solid when weighed in water and the loss when weighed in the liquid, are the respective weights of equal bulks of the water and of the liquid which were displaced by the solid. Hence, to find the specific gravity of the liquid, divide the loss in weight of the solid when weighed in the liquid by its loss in weight when weighed in water.

CHAPTER II

MOLECULAR PHENOMENA

61. The Contraction of Liquids Due to Loss of Heat Indicates That Liquids Are Made Up of Particles Called Molecules. —Scientific study has often led to conclusions widely at variance with opinions ordinarily looked upon as perfectly simple and self-evident. It is usually taken for granted, for example, that water occupies all of the space which it seems to occupy. Even a drop of water, if placed under a microscope, appears perfectly compact, and reveals no empty spaces anywhere within the liquid. Nevertheless, certain experiments suggest that water is made up of particles and that empty spaces actually exist between the particles. Among these experiments, the following are simple and easily performed.

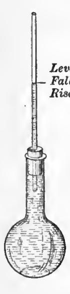


FIG. 55.

Fill a small Florence flask with water having a temperature of about 72 degrees Fahrenheit. Insert one end of a 12-inch piece of fine glass tubing through the hole in a rubber stopper. Force the stopper into the mouth of the bottle, until the water displaced by the stopper rises nearly to the top of the glass tube (Fig. 55). The water may be rendered more readily visible from a distance, if, before it is placed in the flask, it is colored deeply by means of some aniline dye. Cool the water in the flask by placing it in ice-water. The

water in the glass tube falls. That part of the water, which before cooling filled the flask, must now occupy less space, in order to permit a part of the water which was forced up into the tube to return to the flask.

The total amount of water present in the flask and tube is the same both before and after cooling. This is shown by the fact that in a vacuum (§ 52) the water weighs precisely as much at the lower as at the higher temperature. How, then, can water occupy less space at one temperature than at another? It has been suggested that water consists of separate particles, which are slightly distant from one another, and that cooling is a process which brings the particles of water closer together. These separate particles have received the name of *molecules* of water.

62. Increase of Heat Causes the Molecules of Liquids to Move Farther Apart.—If cooling is a process which brings the molecules of water closer together, then the converse also must be true, that heating is a process which causes the distance between the molecules of water to increase.

Prepare the apparatus as in the case of the experiment described in the preceding paragraph. Pour enough water into the flask to fill the flask when closed and to rise in the tube to only a short distance above the level of the stopper. Place the flask on a piece of wire gauze which rests on an iron ring stand. Heat it gently by means of a Bunsen burner or alcohol lamp. The heat affects the glass before it reaches the water. The molecules of glass separate, the flask becomes slightly larger, and the water in the tube, which is still cool, falls. However, for the same increase in temperature, the increase in volume of the water is much greater than the increase in volume of the glass. Therefore, as soon as

the water in the flask is also affected by the heat, the distance between the molecules of water also increases, and the water soon rises rapidly in the tube until it runs out at the top (§ 120).

63. Solids are Composed of Molecules.—The ball and ring apparatus consists of a copper ball attached by a chain to a wooden handle, and of a copper ring fastened at the end of a rod which is also supplied with a handle. When both ball and ring are at the same temperature, the ball will barely pass through the ring (Fig. 56).

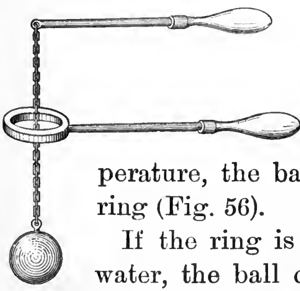


FIG. 56.

If the ring is cooled by means of ice or ice-water, the ball can no longer pass through the ring. Cooling has caused the molecules of copper to move closer together. The copper in the ring now occupies less space, and, in consequence, the diameter of the ring is shortened. The decrease in the diameter of the opening through the ring may be measured by means of a vernier sliding caliper.

Permit the ring to return to its original temperature. Then heat the ball. It increases in size. The ball is now too large to pass through the ring. If, however, the ring also is heated sufficiently, it becomes so enlarged that the heated ball can once more pass through it.

It is necessary to come to the conclusion that copper as well as water is composed of particles or molecules which are not in direct contact with one another. Since the separate particles have never been seen, even by means of the strongest microscope, the molecules of both substances must be exceedingly small, and the distance between them must be very minute.

64. The Distance between the Molecules of Some Liquids Is Sufficient to Permit the Interposition of Molecules of Other Liquids.—If water consists of molecules and these molecules are separated by very minute, but none the less real spaces, the question arises whether it is possible to insert any substances into the spaces between the molecules of water. The following experiment suggests that this may be accomplished successfully.

Pour water into a long tube which is closed at one end (for example, a combustion-tube about half an inch in diameter), until it rises to a level of 7 inches above the base of the tube. Pour 7 inches of alcohol on top of the water, so gently that the liquids do not commingle (Fig. 57, A). Mark the upper limit of the alcohol by a rubber band slipped over the top of the tube. The water and alcohol seem to occupy all the space in the tube for a length of exactly 14 inches. However, when the opening at the top of the tube is closed by means of the thumb, and the tube is repeatedly inverted and turned back to its original position, the volume of the mixture is decreased to such an extent that the length of the tube occupied by the mixture is shortened by about three-tenths of an inch (Fig. 57, B). For some reason the two liquids, when mixed, occupy less space than when kept separate.

FIG. 57.

This shortening of the liquid column can be explained only by the supposition that the molecules of one liquid may slip into the empty spaces which exist between the molecules of the other liquid. Possibly the spaces between the molecules in both liquids are large enough to permit in each case the entrance of some of the molecules of the other liquid.

65. Small Size of Molecules Indicated by Gold Leaf and by Soap-bubble Film.—The smallest particles which can be detected by means of the best microscopes have a diameter of about $\frac{1}{100,000}$ of an inch. Gold has been hammered into leaves so thin that the thickness of a single leaf does not exceed $\frac{1}{300,000}$ part of an inch. If it were possible to remove from this leaf a piece whose width and length did not exceed its thickness, the piece would be invisible even if search were made with the best microscope.

A few moments after a soap-bubble has been blown, rings of color make their appearance at the top of the bubble and travel down its sides. Just before bursting, a black spot becomes visible at the top of the bubble, this spreads, and a moment later the bubble breaks. It has been determined by investigators in physics that the thickness of the colored part of the bubble immediately below the margin of the black area, is about $\frac{1}{240,000}$ part of an inch. The black part of the soap-bubble (just before bursting) is much thinner—according to some investigators, about $\frac{1}{9,600,000}$ of an inch. This thickness is about 100 times as small as the diameter of the smallest particle visible by means of the best microscope.

Although the black part of the film breaks, the cohesion between the molecules composing it is sufficiently strong to enable the film to remain in existence for an appreciable, although very brief, amount of time. It is difficult to conceive of even this degree of cohesion, unless the film consists of several layers of molecules.

If it be assumed that the number of layers of molecules forming the film is at least equal to five, then the diameter of the molecules forming the film does not exceed $\frac{1}{50,000,000}$ of an inch. Molecules, however, are supposed not to be in direct contact with one another, at least not

for any appreciable length of time. Therefore the actual diameter of molecules *must be much smaller* than $\frac{1}{50,000,000}$ of an inch.

From recent mathematical investigations it appears that a single molecule of water taken from a soap film *may be as small as* $\frac{1}{2,500,000,000}$ of an inch in diameter.

66. Relative Size of Molecules.—Molecules of the same substance and under the same conditions are believed to be similar in every respect. The molecules of one kind of substance, however, are believed to differ from those of another kind. Among other things, they differ in size and in weight. For instance, the molecules of mercury are probably larger and heavier than those of water.

The actual size of molecules is unknown. According to some calculations, difficult to explain here, the average diameter of molecules is about $\frac{1}{62,500,000}$ of an inch. It has been calculated that if a globe of water, the size of a football six inches in diameter, were magnified to the size of the earth, the molecules of water would occupy spaces greater than those filled by small shot and less than those filled by footballs. These ideas may not be very definite, but they are the most accurate which the present state of science affords (§ 78, 81).

67. Use of Litmus in Determining the Presence of Acids or Alkalis.—The value of the evidence furnished by the experiment described in the next paragraph will be better appreciated if the use of litmus in chemical experiments be well understood.

The color of litmus is blue tinged with purple. It may be purchased in the form of small cubes which may be dissolved in water, giving to the water a characteristic blue color. A single drop of any acid will change the color of a considerable quantity of the litmus solution

from blue to red. The addition of several drops of any alkali will change the color back to blue once more. Any change to a red color in a litmus solution originally blue indicates, therefore, the introduction of an acid. Any change from red to blue indicates the introduction of an alkali.

The more common acids are sulphuric acid, hydrochloric acid, and nitric acid. Among the common alkalis are ammonia water and caustic potash.

68. Diffusion of Liquids.—Fasten a long test-tube, one inch in diameter, in a vertical position. Nearly fill it with water distinctly colored with blue litmus. Insert a thistle-tube so that its lower end rests upon the bottom of the test-tube. Pour hydrochloric acid into the bowl of the thistle-tube so slowly that, when the acid reaches the bottom of the thistle-tube, its entrance will not produce a perceptible current in the colored water within the test-tube. As soon as the acid reaches the bottom of the test-tube, its presence is at once detected by the change, from blue to red, in the color of the litmus dissolved in the water (Fig. 58).

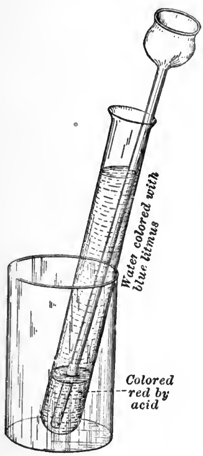


FIG. 58.

Continue to add acid to the thistle-tube until the red color extends a little over half an inch above the bottom of the test-tube. Allow the apparatus to stand for several days, without disturbing either the liquids or the thistle-tube. The red coloring gradually extends to higher and higher levels. This indicates that the molecules of the acid are slowly travelling upward into the litmus solution. If for sev-

eral days a record be kept of the height to which the red coloring has crept, it will be found possible to determine the rate at which the molecules of acid travel up the tubes.

Different substances travel at various rates of speed. Hydrochloric acid travels twice as fast as salt, salt travels three times as fast as sugar, and sugar travels seven times as fast as the albumen of an egg. The name albumen is given by physiologists to the colorless liquid which surrounds the yolk of an egg, and which after cooking becomes hard and white.

Two liquids in contact with one another may become intermingled owing to the wandering of their molecules (§ **71**). This slow process of intermingling is known as *diffusion.*

69. Membranes for Illustrating Osmose of Liquids.—In many cases molecules pass readily through membranes in which even the best microscope can detect no openings. For experimental purposes, the best membrane is the very thin membrane which lines the large masses of suet (fat) found in the interior of the bodies of cattle. These membranes may be easily obtained from any butcher. By exercise of considerable care, this membrane can be removed without rents or punctures.

70. Osmose of Liquids.—If two different liquids or solutions are placed on opposite sides of a membrane, the molecules of both liquids or solutions may pass through the membrane at the same time, but in opposite directions. This may be shown by the following experiment.

Cover the open end of the bowl of a thistle-tube with a membrane and tie it securely by means of a string wrapped around the neck of the bowl. Invert the thistle-tube and insert it vertically in a jar nearly filled with

water. Fasten the thistle-tube securely in this position.

Dissolve in water all the (blue) copper sulphate which the water will hold. If the solution is not clear add a few drops of sulphuric acid. Through a funnel pour the solution into the upper end of the thistle-tube (the narrow end, opposite the bowl, in the present position of the tube), until the level of the copper sulphate solution in the tube is the same as the level of the water in the jar. The level of the copper sulphate solution may easily be adjusted to that of the water by first bringing the two liquids approximately to the same level, and then raising or lowering the thistle-tube until the surface of both liquids is found at exactly the same level. Then allow the apparatus to remain undisturbed for several hours.

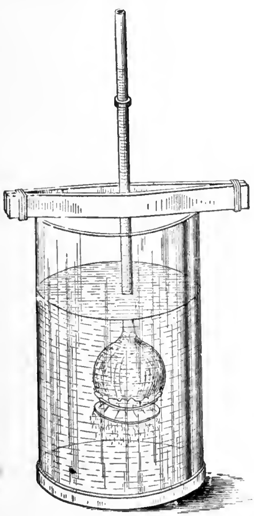


FIG. 59.

In a short time the blue copper-sulphate solution in the tube rises above the level of the water in the jar, and the height reached by the solution increases for several hours (Fig. 59). The rise of the copper-sulphate solution in the thistle-tube can be due only to the passage of water from the jar, through the membrane, up into the bowl of the thistle-tube.

At the same time that part of the water immediately below the thistle-tube becomes tinged with light blue. This indicates that part of the copper-sulphate solution is passing from the bowl, through the membrane, into the water in the jar.

The interchange of the molecules of different liquids through the same membrane in opposite directions at the same time is known as the *osmose* of liquids.

71. Varying Rates of Transference of Molecules through Membranes during Osmose of Liquids.—If the molecules of copper sulphate passed downward through the membrane as rapidly as the molecules of water move in the opposite direction, the level of the solution in the thistle-tube would not change. In the experiment described in the preceding paragraph, however, the level of the copper sulphate rises and that of the water falls. Owing to the much greater width of the jar, the fall of the water level is practically imperceptible. This change in level of the two liquids is evidently due to the fact that the molecules of water pass through the membrane more rapidly than do the molecules of copper sulphate.

The comparative rates of speed shown during the osmose of various liquids and solutions has been studied. Thus, for instance, water passes through a membrane four to six times as rapidly as salt. Since a salt solution is colorless, its motion down into the water cannot be made visible, and for this reason copper sulphate was used in the preceding experiment (see also close of § 68).

72. Osmose of Gases.—Molecules of gases are much more free to move than molecules of liquids. If there be any cohesion between the molecules of a gas, it is so slight that it is impossible to detect this cohesion experimentally.

The molecules of different gases move with different rates of speed. This may be shown by an experiment very similar to the one preceding.

Cement to the upper edge of a funnel the open end of

a long, cylindrical, unglazed earthen-ware jar, similar to the jars used in two-fluid electric cells. Thrust the tube of the funnel vertically through the opening in the rubber stopper which closes one of the necks of a two-necked bottle. Nearly fill the bottle with water. Through the rubber stopper in the second neck thrust a glass tube until the lower end of the tube dips beneath the surface of the water.

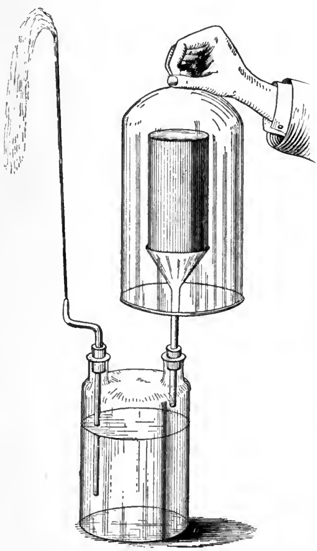


Fig. 60.

The experiment will prove more interesting if before inserting the glass tube in the stopper, the upper end of the tube be drawn out until the opening becomes very small, as directed in § 36.

Fill a bell-jar with hydrogen (a gas already mentioned in §§ 2, 3 and 4; see also §§ 137, 138). Lift the bell-jar and, without disturbing its vertical position, place it above the apparatus and lower it over the earthen-ware jar (Fig. 60). The hydrogen now enters the earthen-ware jar so much more rapidly than the air in the jar can move out in the opposite direction, that the total quantity of gas within the earthen-ware jar is increased. In consequence, the pressure of the mixture of gases in the jar also increases. This mixture of gases presses downward upon the water in the bottle with such force that some of the water passes up the glass tube and out through the small opening in the form of a tiny spray.

73. The Rate of Motion of Molecules of Gases.—Molecules of hydrogen move about four times as fast as the average speed of the molecules forming the mixture of gases called air. It has been calculated that hydrogen travels at the rate of about 9 miles per second. This does not mean that any one particle of hydrogen actually travels that distance in a straight line in the period of one second. In hydrogen which is subjected to the same pressure as ordinary air, the molecules are probably so close together that, before any molecule has gone $\frac{1}{250,000}$ of an inch, it will strike some other molecule of hydrogen which is moving in some other direction. While the speed with which a molecule of hydrogen travels is very great, the distance which it gets from its original position in one second is, owing to these collisions, comparatively small. Still the total change in position, after a number of seconds, is sufficiently great to give rise to such phenomena as those just described in the preceding paragraph.

74. Evaporation.—The fact that the molecules of a liquid are continually changing their position is shown by the phenomena known as diffusion. Moreover, many of the molecules at the surface of a liquid leave the remainder of the liquid and move out into the air. If these molecules do not return to the liquid from which they came, the quantity of liquid contained in the vessel is permanently diminished. That part of the liquid which disappears, is said to *evaporate.*

75. The Evaporation of Solids, or Sublimation.—Liquids are not the only substances which evaporate. If a piece of camphor be exposed to the air for any length of time, it will evaporate completely. The molecules leave the piece of camphor and wander over the room:

They take the form of a vapor, or gas, which is very oppressive to certain insects, and on this account camphor is often placed where the vapor formed by its evaporation will prove offensive to the moths which attack woollen clothing.

Even ice evaporates. If a piece of ice be exposed to dry air in a place where the temperature is much below the freezing point, it will gradually disappear. It passes directly into the state of a vapor without first taking the liquid state. In this manner a thin coating of ice on a stone often disappears during wintry weather, especially when exposed to a strong wind. When clothing just washed is hung out to dry on days when the temperature is below the freezing point, the water in it freezes, and the clothing becomes stiff. During the day, however, a large part of the ice evaporates, especially in case a strong wind is blowing.

The resins and oils found in various kinds of wood, such as pine and cedar, also evaporate slowly. This gives rise to the smell which is characteristic of the various kinds of wood.

When a solid, that is heated, passes directly into the state of a vapor without first becoming liquid, the process is called *sublimation*. A cool body placed in the path of a vapor may cause it to return again to the solid state, in this case also without first assuming the liquid state.

76. The Cause of the Odor of the Rose.—Investigators in physiology have come to the conclusion that we can smell only that with which we actually come in contact. We say that we smell a rose; but in reality we smell only those particles which leave the rose and strike against our nostrils.

The showy part of the flower of the rose consists of the

beautifully colored leaves, called petals. Upon these petals are minute drops of oil. The oil evaporates. This means that some of the molecules of the oil leave the drops of oil found upon the petals, and do not again return to the flower. These molecules of oil move away in all directions, and strike against any bodies obstructing their path. The molecules may come in contact with most parts of our body without our being aware of the fact. Within the nose, however, are nerves especially adapted to perceive the presence of even the very minute quantities of oil which enter the nostrils. When these nerves are bombarded by the molecules of oil coming from the petals of the rose, we are aware of a sensation in the nose, and say—we smell the rose.

This fragrant oil is of considerable value in the manufacture of perfumery. About 2,700 pounds of roses are required to obtain .9 pound of oil, and this weight of roses may be raised on an area of about 1 acre. The odor of pure rose-oil is peculiarly honey-like, and too intense to be agreeable. Its entire deliciousness is developed only by a strong dilution with water, alcohol, or other substances.

77. The Small Size of Molecules shown by the Sense of Smell. — Molecules of substances having disagreeable odors often travel rapidly, and a small quantity is sometimes sufficient to cause discomfort to all the persons in a large room.

A very small particle of musk, $\frac{1}{500}$ of an ounce, will keep a room scented for many years. The number of molecules which leave the slowly evaporating musk must be enormous. Nevertheless, the total loss in weight in several years is so small that it cannot be determined accurately even by means of a delicate balance.

Dogs have been known to track men several days after their feet have left imprints along their line of wandering. Some particles characteristic of the man or of his clothing must have been left behind in his tracks. The total quantity of the particles must be very small, since they cannot be detected by means of a microscope. Nevertheless, the total number of molecules left behind in each imprint must be sufficient to enable the dog to recognize their presence, even one or two days after the tracks were made. Moreover, this is true notwithstanding the fact that, in the meantime, many molecules must have passed away from the imprints. Molecules must, therefore, be very small (§§ 65, 66, 81).

78. Molecules of Solids May Enter between the Molecules of a Liquid.—When sugar is placed in water, it disappears. The sugar is said to dissolve in the water. It has not ceased to exist. If the water be removed by evaporation, the sugar once more may be recovered. When sugar dissolves, the molecules of sugar separate and enter the spaces between the molecules of water. The individual molecules of sugar are so small that, when they have once become separated, they cannot be recognized even under the microscope. When copper sulphate is dissolved in water, the individual molecules separate also, and can no longer be recognized by means of the microscope. But they have not ceased to exist. Even the color of the individual molecules is retained, for every part of the water in which the copper sulphate is dissolved shows the blue color.

79. The Cause of Solution.—What causes the sugar to dissolve in water? A difference in the relative strength of certain molecular forces. One of these forces is the mutual attraction of the molecules of sugar for one another,

which causes them to remain together and form a lump. The second force is the mutual attraction between the molecules of water. The third force is the mutual attraction between sugar and water.

The cohesion between the molecules of sugar is much greater than that between the molecules of water. This is shown by the fact that the point of a knife can be thrust much more readily into water than into a lump of sugar. In order to separate the molecules of sugar, a third force must exist which is stronger than either the cohesion of sugar or the cohesion of water. This third force is the adhesion between the molecules of sugar and those of water.

The mutual attraction between sugar and water is so great that both the molecules of water and the molecules of sugar are drawn apart. Sugar molecules draw apart water molecules, and water molecules draw apart sugar molecules, until finally the same proportion of sugar is found in every part of the water. The solution has become uniform.

80. The Small Size of Molecules Shown by Solutions.— When sugar and copper sulphate dissolve in water, their molecules continue to separate until no particles of sugar or copper sulphate can be recognized even under the most powerful microscope. Since the smallest particles which can be detected by means of the best microscopes have a diameter of about $\frac{1}{100,000}$ of an inch, molecules of sugar and of copper sulphate are smaller than $\frac{1}{100,000}$ of an inch.

When $\frac{1}{1200}$ of an ounce of indigo is dissolved in sulphuric acid, it gives a distinctly blue color to one cubic foot of water. This is equivalent to $\frac{1}{440,000,000}$ of an ounce of indigo to a drop of water. Nevertheless, each

drop of water is evenly tinged with blue. In order that such a small quantity of indigo may give an even tinge of blue to each drop of water, the number of molecules in even $\frac{1}{440,000,000}$ of an ounce of indigo must be large. In order that many molecules may exist in $\frac{1}{440,000,000}$ of an ounce, the molecules must be exceedingly small (§§ 65, 66, 78).

81. The Sense of Taste.—Absolutely insoluble materials are tasteless. If the substances are not already dissolved in some liquid, in order to be tasted they must be dissolved in the saliva, as soon as they are placed within the mouth. Those substances which are most readily dissolved are most easily tasted. Sugar and salt are good examples. In the juices of many fruits, sugar and other substances are already dissolved. It is owing to the presence of the dissolved sugar that the tastes of many fruits are so agreeable.

The sense of taste is caused by the motion of the dissolved molecules. Located in different parts of the mouth, especially upon the tongue, are certain nerves which are very susceptible to the irritations caused by the motions of some kinds of molecules, while indifferent to the motions of other kinds. When the molecules of many of the dissolved substances come in contact with these nerves, a sensation is produced known as the *sensation of taste*. The nerves are called the nerves of taste.

82. The Amount of a Substance Which Can Be Dissolved by a Liquid Depends upon the Temperature of the Liquid.—The quantity of a solid which will dissolve in a liquid depends in some manner upon the distance between the molecules of the liquid. As the molecules of the liquid move farther apart, the space available for the molecules of the solid increases, and a greater amount of the solid

can be dissolved. The distance between the molecules of any substance depends upon its temperature, and increases (with few exceptions), as the temperature increases. The amount of a solid which can be dissolved in a liquid depends, therefore, upon the temperature of the liquid.

Water at 150 degrees Fahrenheit will dissolve more sugar than the same quantity of water at 100 degrees Fahrenheit. When sugar is placed in water already saturated with sugar, the sugar last added falls to the bottom of the solution and remains there undissolved.

Corresponding to each degree of temperature there is a definite distance between the molecules of the liquid, and a definite quantity of the solid which can be dissolved. When at this temperature the liquid has dissolved all the material which it can hold, it is said to be a *saturated solution.* This solution will be a saturated solution as long as its temperature remains constant. Raising the temperature of a saturated solution, therefore, places it in an unsaturated condition, for if its temperature be raised, the liquid can dissolve more of the solid.

83. The Cooling of a Saturated Solution Causes the Exclusion of a Part of the Dissolved Solid.—If a saturated solution is cooled, the spaces between the molecules of the liquid decrease, all of the solid can no longer be held in solution, and a part is crowded out of the liquid. The quantity of the solid excluded depends upon the amount of fall in temperature of the liquid. The forced-out molecules of the solid settle upon the sides and bottom of the vessel holding the solution.

84. Evaporation Causes an Exclusion of Part of the Dissolved Material.—In a saturated solution all the spaces available between the molecules of the liquid are occu-

pied by the molecules of the dissolved solid. When a part of the liquid evaporates, the molecules of the solid which were between the molecules of that portion of the liquid which has evaporated cannot pass into the spaces between the molecules of the liquid which is left in the vessel, because the spaces are already filled. These molecules then settle upon the sides and the bottom of the vessel. As the liquid continues to evaporate, the crust of the solid material upon the walls of the vessel increases in thickness. If all of the liquid evaporates, all of the solid which was in solution is left behind in the vessel.

The evaporation may be brought about either by subjecting the solution to heat, or by exposing it to air at ordinary temperatures. In the first case, evaporation will be rapid. In the second case, it will be much slower.

85. Crystallization. — When molecules are slowly excluded from a saturated solution, either by very slow cooling or by evaporation, the molecules often do not form a crust of even thickness on the walls of the vessel, but collect in groups. If, before cooling or evaporation is begun, a small fragment of the solid is lowered into the liquid by means of a string, the excluded molecules seem to collect by preference upon this fragment. In this manner groups of molecules of unusual size may be secured at the end of a string, and the quantity of molecules settling upon the sides and the bottom of the vessel may be considerably reduced.

If these groups of molecules be examined very carefully, it will be discovered that they consist of a combination of smaller groups called *crystals.* The surface of each crystal is made up of a number of flat smooth faces which join each other along straight edges. Crystals of

the same substance formed in the same solution usually resemble each other very much in form, although their faces are usually not all of the same form and size. Even when the bases of these crystals are grown together so that only the free surfaces of the crystals can be examined, their similarity in form may be recognized. In order to make evident their similarity in form, crystals must be placed so that the corresponding faces of the different crystals which are inclined toward one another at the same angles occupy the same relative positions.

86. Solids may be Recognized by the Form of their Crystals. —A careful study of the crystals of different kinds of solids shows that crystals composed of the same kinds of

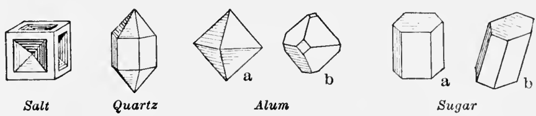


FIG. 61.

molecules are constructed on the same general plan. This is usually easily recognized when the crystal faces are not large. On the other hand, when crystals composed of one kind of molecules are compared with crystals composed of another kind, it is noticed that the crystals differing in composition are usually dissimilar in form (Fig. 61). It is possible, therefore, to recognize substances by the form of their crystals. It is not very likely that this can be done readily and with confidence by beginners, even in the case of crystals of very common substances. But an examination of a few crystals, such as those of salt, quartz, and alum, will give a fair idea of the principle involved.

Crystals of salt have six principal rectangular faces, ar-

ranged like the faces of a cube. All the faces, therefore, form angles of 90 degrees with the immediately adjoining faces.

Crystals of quartz have the form of a six-sided prism, terminated at each end (if both ends are free) with a six-sided pyramid. The faces of the prism meet each other at angles of 120 degrees. The faces of the prism meet the faces of the pyramid at angles of about 140 degrees. The alternate faces of the pyramid are sometimes slightly rougher in appearance than the intermediate faces.

Crystals of alum are formed by a combination of two geometric forms, the octohedron and the cube. The typical octohedron consists of two similar pyramids, facing in opposite directions and united along their base. Each pyramid consists of four triangular faces. All the faces are identical in form; they are equilateral triangles. The faces of the octohedron meet along straight edges at angles of about 110 degrees. The cube consists of six rectangular faces meeting each other at angles of 90 degrees. In the combination, the faces of the cube usually appear like little faces cutting off the corners of the octohedron. The faces of the cube and those of the octohedron meet at angles of about 125 degrees.

Crystals of sugar are more complex in form. While not readily described in language which those not familiar with geometry will easily understand, the fact that they have a characteristic form of their own (monoclinic) is readily recognized.

87. Crystals Suggest that the Molecules of Different Substances Differ in Form.—No matter whether large or small, whether single or in groups, whether presenting their natural color or giving evidence of being stained by foreign substances, crystals composed of the same

kinds of molecules possess the same general form. This shows that they have been developed in accordance with the same general plan.

It is difficult to understand how this can be possible, if all molecules of the same kind do not follow the same relative arrangement in all crystals. The remarkable uniformity of the arrangement of the molecules is shown in a striking way by the wonderfully even surface of the flat faces of the crystals. Few objects in nature are as absolutely smooth as are many of the faces on the smaller-sized crystals of most minerals. The absolute identity of the angle made by corresponding faces of crystals composed of the same kind of molecules further indicates the absolute identity in the arrangement of the molecules. How is this arrangement possible, if molecules of the same substance are not exactly alike in size and form?

The reason why *crystals* of different substances differ in form must be because the *molecules* of different substances also differ in size and form.

88. Large Crystals Produced by Slow Cooling or Evaporation.—Molecules excluded from a saturated solution by cooling or evaporation do not settle with equal readiness upon all objects with which they come in contact. They seem to display a kind of preference for certain locations. For instance, they are more apt to settle upon rough bodies, such as strings and pieces of wood, than upon smooth objects. But the greatest preference seems to be shown for crystals composed of molecules identical in kind with those which are seeking a location. For this reason the crystals first formed usually grow much more rapidly than those which come into existence at a later time. Even fragments of crystals lowered into the

solution by means of strings form good collecting centres, if they consist of the same kind of molecules as those which are being excluded from the liquid. By their use the likelihood is much increased of securing large crystals which may be removed easily from the vessel.

In order to secure large crystals of salt, dissolve a considerable quantity of salt in water, until the salt last added remains undissolved even after considerable stirring. Set aside the vessel containing the solution, in a place where evaporation will take place very slowly. As the water gradually evaporates, the crystals will develop. In several weeks fine large crystals may be obtained.

In order to secure large crystals of alum or sugar, dissolve as much of the solid as possible in hot water. Tie a piece of the solid at the end of a string and lower it into the liquid. Then allow the saturated solution to cool very slowly. In the case of sugar the temperature of the heated water should not be raised above 140 degrees Fahrenheit and, while crystallization is taking place, the temperature should never be allowed to fall below 70 degrees Fahrenheit.

Good crystals of quartz can easily be purchased from any dealer in minerals. (A. E. Foote, Philadelphia.)

89. Small Crystals Produced by Rapid Cooling or Evaporation.—In the formation of crystals of large size, the rate of cooling seems to be a very important element. It takes time for molecules to travel through any liquid. If there be ample time, most of the excluded molecules find their way to the crystals first formed, so that the first formed crystals show the greatest growth. If, however, the solution be cooled rapidly, the molecules of the solid in solution are excluded so rapidly and in such

great numbers that, before they can reach the crystals already in existence, they form new groups at many points within the liquid. These groups form new centres of collection, so that, in case of rapid cooling, crystals are formed simultaneously throughout the liquid. These crystals may at first be so small that they can be recognized only by means of the microscope. If they are very numerous, the solution simply assumes to the naked eye a turbid appearance.

Granulated sugar and the finer grades of table salt are produced by rapid evaporation accompanied by continual stirring, in order that the small crystals, which are in process of formation throughout the liquid, may not grow together. When the crystals are of proper size the liquid is withdrawn or the crystals are removed. The rate of cooling may be so rapid that the molecules cannot find time to arrange themselves in an orderly manner. They then form upon the walls and the bottom of the vessel a coating which gives no evidence of crystallization.

The lavas which have poured out from the volcanoes in different parts of the world have cooled with such varying degrees of rapidity that some of them have turned into a mass of crystals, while others show no more than the faintest trace of crystallization. Under the microscope all gradations may be seen between lavas composed entirely of crystals, and lavas which are practically without trace of crystallization.

CHAPTER III

HEAT

90. The Three States of Matter.—It is a familiar fact that water may exist under three different forms. It may be a solid, a liquid, or a gas. When solid, it is called ice, when liquid, it is called water, and when gaseous, it is called steam. The word water may also be used, in a general sense, so as to include all forms of water. In this case ice is looked upon as solid water, and steam as water in the gaseous state.

It is not so well known that many other substances also exist in three forms. The chief reason for this lack of information is the fact that few substances are as useful as water, in all three forms in which they can exist. Few substances, therefore, have been studied as carefully as water. Paraffine, sealing-wax, lead, and iron are all solids at ordinary temperatures, but when paraffine is used to form thin layers over jelly so as to exclude the air, and when sealing-wax or lead is employed to seal fruit jars, these substances are first melted. When it is desired to cast lead into the form of bullets and iron into the form of stoves, they must first be liquefied and then poured into moulds. It is, therefore, well known that these substances exist both as solids and as liquids, but it is not so well known that some of these can also exist as gases. Nevertheless, paraffine can easily be heated sufficiently

to be turned into a gaseous form, and, in the enormously heated atmosphere of the sun, lead and iron exist in the form of gases.

Another reason why the existence of many substances in all three forms is unknown, is because in many substances some of these forms require extremely high or extremely low temperatures. Most metals, for instance, assume the gaseous form only at very high temperatures, and many of the more common gases become liquid and solid only at very low temperatures. For this reason, air, which is composed almost wholly of two gases, one part of oxygen and four parts of nitrogen, has been known in the liquid, and even in the solid state, only within the last twenty-five years.

As far as known all substances when sufficiently cooled, assume the solid state. Some substances change from gases into solids or from solids into gases, directly, without assuming the intermediate liquid state (§ 75). Many solids, when heated beyond a certain temperature, do not turn into liquids, but change their nature entirely. Wood, for instance, when heated beyond a certain temperature, does not become liquid, but burns ; it changes into ashes and certain kinds of gas. Changes of this kind will be more fully studied later (§ 195).

The general fact remains, that there are three states of matter. The changes of matter from one state into another are accompanied by interesting phenomena. The phenomena will be studied in the following paragraphs, water being taken as a familiar example.

91. The Temperature of Ice Is Variable.—The temperature of a piece of iron exposed to the open air varies with that of the surrounding atmosphere. In summer it is warm, and in winter it is cold.

In a similar manner the temperature of a piece of ice varies with the surrounding atmosphere. At Werkojank in Siberia the temperature of the air has been known to fall to 90° below zero, Fahrenheit, or 122° below the freezing point. This is the coldest region so far discovered on our globe. The temperature of the ice exposed to the air in this locality must also fall to 90° below zero.

In Ohio, temperatures of 15° below zero, or 47° below the freezing point, are not frequent, but occur often enough to be within the experience of anyone who has lived within the State ten or more years. During the existence of such cold weather, the temperature of ice also falls to 15° below zero. Place the thermometer in snow on some day when the temperature of the air is much below the freezing point of water. When the weather becomes warmer, the temperature of ice rises, and when the temperature of the air exceeds 32° above zero, the ice melts.

Ice-cream, at a temperature of 32° F., will melt readily in summer time. But if its temperature be reduced considerably below 32° F., it will remain in a frozen condition until its temperature has risen to 32° F., when the process of melting begins. For this reason caterers sometimes lower the temperature of ice-cream which is intended for evening parties, so much that it may become a little warmer and still be in fit condition to eat several hours after it has been delivered (§ 114).

92. The Temperatures of Water and Steam are Variable.— That the temperature of water varies considerably is too familiar a fact to require special mention. Between the freezing point, 32° F., and the boiling point, 212° F., there is a difference of 180 degrees.

It is not so well known, however, that the temperature of steam may also vary considerably. At ordinary pressures of the atmosphere, at sea level, water is converted into steam soon after its temperature reaches 212° F. The steam which is formed also has a temperature of 212° F. If the steam is placed in a closed vessel, its temperature may easily be raised considerably above 212 F. The steam generated in the boiler of an engine always rises above this temperature. When the temperature of steam is so great that no water is present in a liquid condition, even in the form of a mist, the steam is said to be dry.

93. The Temperature at which Liquefaction and Solidification Take Place.—At ordinary pressures of the air, ice melts at a temperature of 32° F. This temperature is known as the *melting point* of ice. Other substances do not melt at this temperature but have their own characteristic melting points. Mercury, for instance, melts at 40° below zero, Fahrenheit, paraffine melts at 129° above zero, sulphur at 239°, tin at 449°, lead at 619°, zinc at 773°, silver at 1749°, copper at 1930°, hard glass at 2012°, nickel at 2642°, and iron at 2912° F.

Many substances melt at temperatures so low that they are never seen in a solid state except in laboratories where very low temperatures are produced artificially. This is especially true of many gases, which are not only never seen as solids outside of laboratories, but which are never seen even as liquids, excepting under similar conditions.

The fact that different substances melt at different degrees of temperature is utilized in a number of ways. Lead, zinc, copper, and glass, for instance, may be readily melted in a vessel constructed of iron. Why?

If water is cooled sufficiently it freezes. The temperature at which it freezes is the same as that at which it melts. In other words, the point of liquefaction is also the point of solidification. This is also true of other substances.

94. The Temperature at which Ebullition and Condensation Take Place.—When subjected to a pressure of one atmosphere, the ordinary pressure of the air at sea level, water boils at a temperature of 212° F. This temperature is known as the *boiling point* of water. Other liquids do not boil at this temperature but have their own characteristic boiling point. Under a pressure of one atmosphere, ether boils at 95°, alcohol at 172°, turpentine at 319°, and mercury at 662° F.

Some substances boil at such low temperatures that they are never seen in the liquid state except in laboratories. They are usually known only in the form of gases. This is true of hydrogen, nitrogen, oxygen, and carbon dioxide.

The fact that different liquids boil at different temperatures is utilized in the separation of various substances by means of distillation. If a mixture of water and alcohol is heated above the boiling point of alcohol and below that of water, the alcohol passes off in the form of a vapor, while the water will be left behind. If the alcohol vapor is passed through a coil of tin or copper pipe placed in cold water, the alcohol vapor is chilled and returns to the liquid state. It may thus be secured nearly free from water.

95. Change in Volume during Solidification and Liquefaction.—The passage of any substance from a liquid to a solid state is invariably accompanied by a change of volume.

Water expands on turning into ice. It increases about $\frac{1}{11}$ in volume (Fig. 62). The result is that when water freezes in a pipe which has no outlet, it often bursts the pipe. The water in a pitcher freezes at the surface first. The layer of ice thus formed serves as a huge stopper, preventing the escape of the water beneath. If any considerable part of the water in the lower part of the pitcher freezes, the pitcher is likely to break. Since water expands on turning into ice, ice is lighter than water, and floats on the water. Beneath the layer of ice covering the river during winter, the water still has a temperature of 32° F., or slightly above. At this temperature the kinds of fish found in northern climates can live.

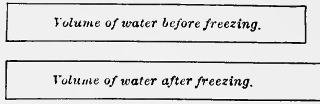


Fig. 62.

Most liquids contract on assuming the solid state. Water is one of the most notable exceptions. Owing to the abundance of water, and its great importance, both in maintaining life and in making possible many lines of manufacture, the exceptional behavior of water is more familiar than the general behavior of other liquids.

When solids pass into the liquid state their change in volume is exactly the reverse of the change which takes place during solidification.

96. Changes in Volume during Ebullition and Condensation.—The passage from a liquid to a gaseous state is invariably accompanied by an increase of volume.

When water at a temperature of 212° F. is changed to steam at 212° F., it does not change in temperature, but it does change its state, and this change is accompanied by an enormous change in volume. A cubic inch of water at 212° is converted into 1696 cubic inches, or

nearly one cubic foot, of steam having the same temperature (Fig. 63). Water furnishes, bulk for bulk, a greater volume of gaseous material than any other liquid. This enormous expansion is accompanied by great force, and is utilized in all the numerous kinds of steam-engines.

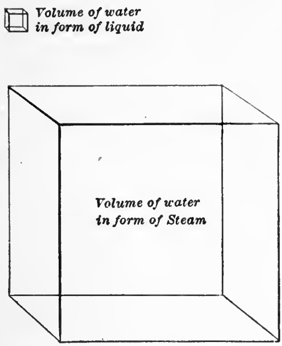


FIG. 63.

The return from a gaseous to a liquid state is always accompanied by a considerable decrease in volume.

97. For the Same Increase of Temperature, Gases Expand More than Liquids, and Liquids Expand More than Solids.—A considerable number of well-known substances remain in the solid state when raised to a temperature of 70° F. A large number are always in the liquid state, and a much smaller number are always in the gaseous state, at this temperature.

If now equal volumes of a variety of substances are chosen, some of which are in the solid, and others in the liquid, or gaseous, states at 70° F., and if their temperature is raised from 70° to 71° F., it is found that all increase in volume, but that the amount of increase is not the same in all cases. All gases expand at the same rate for the same increase of temperature, but the rate of expansion of different liquids and solids varies considerably. In a general way it may be stated that for the same increase in temperature, liquids expand on the average about 20 times, and gases about 70 times as much as solids. The figures secured will naturally vary with the solids and liquids chosen for comparison.

This fact is true also of different states of the same substance. For instance, the amount of increase in volume of water for a rise of one degree in temperature is greater for water in the gaseous state than for water in the liquid state, and for water in the liquid state than for water in the solid state. These changes in volume without a change of state are, however, very small as compared with the changes in volume during any change from one state to another (§§ 95, 96).

98. Effect of Pressure on the Melting Point.—Water expands on turning into ice. Under a pressure of one atmosphere, water freezes at a temperature of 32° F. If the pressure on the water is increased, there is a corresponding resistance to the increase of volume, and water must be cooled to a temperature below 32° F. before it will expand violently enough to freeze. Pressure does not assist in the freezing of water. It interferes. An increase in pressure of a thousand pounds per square inch, lowers the freezing point of water about 1° F.

When ice melts, it decreases in volume. An increase of the pressure exerted on the ice tends to make it occupy less volume. If the temperature of the ice is as high as 32° F., the ice can occupy considerably less volume by becoming water. Pressure, therefore, assists in melting ice.

When particles of ice in the form of snow are pressed together, they melt slightly at the surface. Immediately on removing the pressure, the water formed turns again into ice. The ice crystals become united at their surfaces and a snowball is the result. When the rivers of ice called glaciers pass over rocks, the ice is pressed against the rock, and melts. The water thus formed turns into ice again immediately on passing the obstruction. In

this way ice is able to flow down valleys and to follow the irregular curves along the sides and the bottom of the valley and yet may arrive at the foot of the glacier in the form of compact ice.

Solids which expand on melting, when subjected to pressure, will have their melting point raised instead of lowered.

99. Effect of Pressure on the Boiling Point.—Water subjected to a pressure of one atmosphere boils at a temperature of 212° F. When water at this temperature turns into steam it increases in volume 1696 times. In order to turn into steam, therefore, water must occupy 1696 times as much space, and in order to secure this space it must push back the overlying air.

The force which water must exert in order to expand into steam depends upon the pressure which the atmosphere exerts upon the water. If the atmosphere presses upon the water with greater force, the water must expand with greater force in order to turn into steam. If, on the contrary, the pressure of the atmosphere upon the surface of the water is less, the water need not exert so much force in order to turn into steam.

The force which the molecules of water must exert in order that water may turn into steam, must be sufficiently energetic to cause the molecules to leave the water remaining in the vessel, and to enable them to pass off into space. The motions of molecules which enable them to move about, become more energetic as their temperature increases. Hence in order that molecules of water may escape in the form of steam, their temperature must be greater when the atmospheric pressure is greater, and their temperature need not be so high when the atmospheric pressure is less.

Increase of pressure raises the boiling point of a liquid; decrease of pressure lowers the boiling point.

100. Determination of Elevation by Boiling Point.—Since the pressure exerted by air varies with the elevation of the object pressed upon (§ 13), the force which water must exert in order to turn into steam also depends upon the elevation above sea level. At a greater elevation less force is required, at a lower elevation a greater force is necessary. Hence at a greater elevation water boils at a lower temperature, and at a lower elevation a higher temperature is required. If a table be prepared giving accurate information on the relationship between boiling points, atmospheric pressures, and elevations, the boiling point of water at any locality may be used as a means of determining its elevation.

In a general way it may be stated that a lowering of 1° F. in the boiling point of water is equivalent to a rise in elevation of approximately 538 feet. At Quito, the highest city in the Andes of South America, water boils at a temperature of 194.2 F. This is 17.8° F. below the boiling point of water at sea level. Therefore, the elevation of Quito is approximately $17.8 \times 538 = 9574.4$ feet. At what temperature does water boil at the locality in which you live? What, therefore, is its elevation above sea level approximately?

On the top of Mount Blanc water boils at a temperature of 185.8° F. Eggs cannot be cooked in water boiling at this temperature. Many other cooking operations requiring water boiling at higher temperatures cannot be carried on in open vessels at these elevations.

In boilers connected with high-pressure engines the boiling point is often raised to temperatures exceeding 300° F.

101. Relation between Atmospheric Pressure and Evaporation.—When water evaporates, the molecules separate and form a vapor which passes off into the air. The greater the pressure of the atmosphere, the greater is the difficulty with which the molecules of the water can pass off into the air. Therefore, evaporation takes place much more readily in localities where atmospheric pressure is low.

The relationship between atmospheric pressure and evaporation are very similar to those between atmospheric pressure and ebullition, or boiling.

In the evaporation of syrups during the manufacture of sugar, the operation is carried on in large air-tight chambers from which the air and the vapor formed by the evaporation are removed by an air-pump. The space above the syrup approaches so nearly to the conditions of a vacuum, that the molecules of the water are far less impeded in their efforts to leave the surface of the liquid. Evaporation takes place, therefore, much more readily and at much lower temperatures, when sugar is heated in vacuum-pans. This is done in order to keep a temperature sufficiently low so as not to burn the sugar.

102. Difference between Intensity and Quantity of Heat.—A further study of the phenomena involved in the change of a body from a solid to a liquid, or from a liquid to a gaseous state, makes it desirable to have an accurate idea as to the quantity of heat which is necessary to produce these changes.

The conception of quantity of heat is not so familiar to most persons as the conception of intensity of heat. The intensity of heat shown by a body is known as its *temperature*. The unit of temperature is called a *degree*. The position of the top of a column of mercury at various

degrees of temperature is marked off on the scales of thermometers, and by means of these instruments the temperature of a body can be directly measured.

An ounce of red-hot iron (at a temperature of about 1000° F.) possesses a much greater intensity of heat than boiling water at a temperature of 212°. The intensity of heat does not depend upon the quantity of material, but merely upon the question, how hot it is. Therefore, an ounce of red-hot iron has much greater intensity of heat, notwithstanding the small quantity of iron, than a barrel of boiling water.

Which, however, possesses the greater quantity of heat? Suppose that on a cold winter day the ounce of red-hot iron and the barrel of boiling water be placed in separate rooms, both of small size and having the same temperature. Which will heat up the air in the room to the higher temperature,—the ounce of red-hot iron or the barrel of boiling water? Unquestionably, the latter. Or, suppose that the ounce of red-hot iron and the barrel of boiling water be placed in large tanks half full of snow? Which will melt the most snow? Again, unquestionably the barrel of boiling water. Which, therefore, possesses the greater quantity of heat? The barrel of boiling water.

From this it may be seen that the quantity of heat depends not only upon the temperature of a body but also upon the quantity of material contained in that body.

103. The Unit of Quantity of Heat.—In order to compare different quantities of heat, it is desirable to have some method of measuring this quantity. When we wish to measure length, we use a wooden or steel rule upon which feet, inches, and parts of inches have been carefully marked. When we wish to measure weight, it

is sufficient for ordinary purposes to use some form of a balance accompanied by a set of known weights. The intensity of heat is measured by means of a thermometer supplied with a scale upon which the degrees are indicated. But there is no instrument to determine the *quantity* of heat. Therefore the quantity of heat contained in a body must be determined indirectly by drawing conclusions from some of the effects which the heat contained is able to produce. In practice, the quantity of heat contained in a body is determined by noticing through what range of temperature it will raise a known quantity of water.

Just as there must be definite units in order to measure length, weight, and temperature, so there must also be some definite unit in order to measure quantity of heat. The unit here accepted is the quantity of heat which will raise the temperature of one pound of water from 32° F. to 33° F. This unit is called a *calorie*.

Within ordinary ranges of temperature it takes very nearly the same quantities of heat to raise a pound of water one degree in temperature, no matter what be the temperature of the water to which the additional heat is applied. For this reason it is sufficiently accurate for most purposes to assume that any quantity of heat which raises one pound of water 1° F. above its original temperature is equal to a calorie. Therefore, to raise one pound of water 15 degrees would require 15 calories, and to raise 10 pounds of water 8 degrees would require 80 calories.

This rule applies only to water in the liquid state. To raise one pound of ice one degree in temperature requires .504 calorie, and to raise a pound of steam through an equal range of temperature requires .4805 calorie.

104. Heat Consumed during Change of State, from Solid to Liquid, or from Liquid to Gas.—Heat is consumed in raising a body from a lower to a higher temperature. Heat is consumed, for instance, in raising a pound of ice from a temperature of 10° F. to 32° F., in raising the water from 32° to 212°, and in raising the steam from 212° to 250°. From the concluding statements in the preceding paragraph it may be seen that the quantities of heat required in the three cases just mentioned are about 11, 180, and 19 calories respectively.

Is any heat consumed in changing a body from a solid to a liquid or from a liquid to a gaseous state? If any heat is consumed in any of these operations, the thermometer does not indicate it.

If, for instance, ice be taken at 10° F. and be slowly heated in a vessel over a Bunsen burner, a thermometer imbedded in the ice will show a rise in temperature until a temperature of 32° F. is reached. Then for some time, notwithstanding the fact that heat is being continually consumed by the ice, the thermometer will show no rise in temperature. During this time the ice is melting.

As soon as all the ice has melted, the rise in temperature again begins, and the mercury in the thermometer moves up steadily until it indicates a temperature of 212°. Then the mercury in the thermometer once more becomes stationary. Notwithstanding the fact that heat is being consumed by the water, no rise in temperature takes place. During this time the water is changing into steam. When all of the water has been changed into steam, the temperature once more rises provided the steam is confined in a vessel so that it cannot escape. If it is desired to raise steam to very high temperatures, it must be enclosed in very strong vessels, otherwise the

rapidly increasing pressure of the steam may cause an explosion.

Since the temperature of the ice when it begins melting is 32° F., and since the temperature of the water immediately after melting has taken place is also 32°, it is evident that the heat consumed has not been utilized in causing a rise in temperature, but must all have been used in effecting the change of state from solid ice to liquid water.

In the same manner all the heat which was applied to the water while it was changing into steam, was consumed in changing liquid water into gaseous steam. None of it was utilized in effecting a rise in temperature.

105. Quantity of Heat Necessary to Change Ice to Water. —Heat is consumed in changing ice to water. In order to determine the quantity of heat necessary for this purpose, the experiment must be conducted so that all the heat used shall be employed solely for converting ice into water. None of it must be used to raise the temperature of ice from some lower temperature up to the melting point, 32° F., and none of it must be used to raise the water resulting from the melting of the ice from its original temperature, 32° F., to any higher temperature. This can be accomplished if the ice experimented upon has a temperature of 32° F. at the beginning of the experiment, and if the experiment is stopped the instant all the ice has changed to water, before any of the water formed by the ice has been raised above its original temperature.

From a number of experiments it has been learned that, if one pound of ice having a temperature of 32° F. be placed in one pound of water at 174° F., all of the ice will be melted by means of the heat derived from the

pound of hot water. As fast as the ice melts, the water thus formed mingles with the water used in the melting of the ice. The temperature of this mixture falls as the ice melts, and after the ice is all melted the temperature of the water (including both the original water used and that derived from the melted ice), is found to be 32° F. At this moment, the temperature of both the water resulting from the melting ice and the water whose original temperature was 174° is found to be the same, namely, 32°. This was also the temperature of the ice. The ice turned to water without any change of temperature. The temperature of the pound of water used in melting the ice fell 142°.

The change of state from ice to water was caused by the quantity of heat supplied by the hot water during its fall of temperature. Since, to fall one degree, a pound of water must give out 1 calorie, to fall 142 degrees it must give out 142 calories. Therefore 142 calories were consumed in melting the pound of ice. One hundred and forty-two calories of heat may also be supplied by 2 pounds of water falling 71°, or by 3 pounds of water falling 47.33 degrees. If, therefore, a pound of ice at 32° is placed in two pounds of water at a temperature of 103° F., or in three pounds of water at 79.33° F., the same result is obtained as in the preceding experiment. Sufficient heat is given out to melt all of the ice. If less heat is supplied, all of the ice does not melt. If more heat is supplied, the ice firsts melts and then the water thus formed is raised in temperature.

106. Total Quantity of Heat Necessary to Melt Ice and to Raise the Temperature of the Resulting Water.—If it be desired to change a pound of ice at 32° to water at a temperature of say 60°, this can be effected by placing the

ice in water of such quantity and temperature that it will give up sufficient heat both to change the ice to water and also to raise the water from a temperature of 32° to that of 60°. The amount necessary is a total of 170 calories. This can be secured by taking 2 pounds of water having a temperature of 145°, or five pounds of water having a temperature of 94°.

One hundred and eighty calories of heat are necessary to raise a pound of water from a temperature of 32°, the freezing point, to a temperature of 212°, the boiling point. Almost as many calories of heat, 142, are necessary merely to change the ice to water, without raising its temperature at all. All of this heat is necessary to weaken the cohesion between the molecules to such an extent that the molecules, which are only moderately movable in the case of ice, may change their position with the greatest of readiness in the form of water. This ready change of position of the molecules is characteristic of all substances while in the liquid state.

Instead of using the heat supplied by water, the heat given out by a Bunsen burner may be used in these experiments. But in that case it would be difficult to estimate the number of calories of heat supplied by the burner during the change of ice to water.

107. Rough Estimation of Quantity of Heat Necessary to Change Water to Steam.—With the same source of heat, for instance the flame from a small Bunsen burner, it takes about $5\frac{1}{3}$ times as long to change any quantity of boiling water into steam as it does to raise the same quantity of water from the freezing point, 32°, to the boiling point, 212°. Therefore it may be said that it takes about $5\frac{1}{3}$ times as much heat to convert water into steam as it does to raise water from the freezing to the boiling point.

Since it requires 180 calories to raise one pound of water from the freezing to the boiling point, it will require $5\frac{1}{3} \times 180$, or about 960 calories, to convert one pound of water at 212° into steam. This is only a rough estimate, and if the experiment be attempted, the results might not be so satisfactory, but it will serve to give a conception of the quantity of heat necessary to cause the conversion of water into steam.

108. The Quantity of Heat Necessary to Change Water into Steam may be Determined Indirectly.—The amount of heat necessary to change water into steam is not usually determined directly. Instead of finding how many calories of heat are necessary to change a pound of water into a pound of steam, the experimenter determines how many calories of heat the steam is able to give out when it returns from its condition of steam to that of water. If, for instance, a certain quantity of steam at a temperature of 212°, on changing to water at a temperature of 212°, can be shown to give out 100 calories of heat, it may justly be assumed that 100 calories of heat are necessary also to change that weight of water to steam.

The number of calories given off by the steam may be determined by noticing the rise in temperature produced in one pound of water by a given quantity of steam. If, for example, any given quantity of steam is found to raise the temperature of one pound of water from 60° to 80° it is a safe conclusion that the steam has given out 20 calories of heat. This is the method used in the following experiment.

109. Exact Determination of Quantity of Heat Necessary to Change Water into Steam.—Place a Florence flask on a piece of wire-gauze covering one of the rings of an iron ring stand (Fig. 64). Half fill the flask with water.

Close the flask with a one-hole rubber stopper and through the single opening passing through the stopper thrust one end of a glass tube.

At some distance from the Florence flask place a second vessel. Pour into the vessel a known quantity of water, for instance, one pound. Close the vessel with a rubber stopper perforated by means of three openings. Through one opening thrust a glass tube so that its lower end will extend nearly to the bottom of the water in the

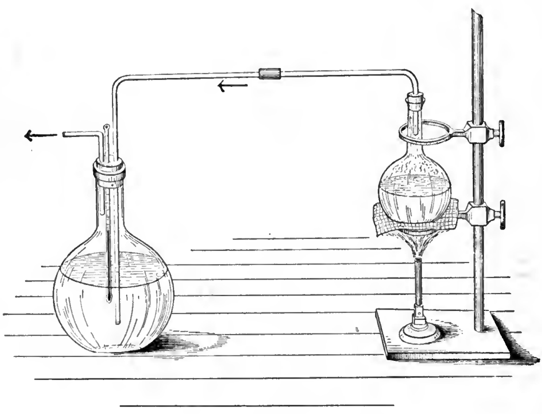


FIG. 64.

vessel, and connect the upper end of this tube with the Florence flask. Through the second opening insert a chemical thermometer so that the bulb will dip into the water. Through the third opening thrust a glass tube bent in such a manner that if any of the escaping steam condenses into water, the water will not be able to return to the vessel. Determine the temperature of the water in the vessel carefully by means of the thermometer. Disconnect the Florence flask temporarily from the ves-

sel and heat the water in the flask until steam is given off freely. Then quickly reconnect the flask with the vessel and continue the formation of steam in the flask.

The steam formed in the flask will leave by means of the glass tube. It will pass along the tube and will escape at its other end into the water which occupies the lower part of the vessel. As the steam rises through this water, it is cooled by the water and returns to the liquid form. In so doing it gives up to the water that part of the heat which was formerly necessary to convert the steam, from its original liquid, to its later gaseous form. Any steam which escapes from the vessel must still have a temperature of 212°, otherwise it would no longer be in the form of steam, and, since it cannot have given up any part of its heat to the water, its escape will not in any way affect the results of the experiment.

If the pound of water at the beginning of the experiment had a temperature of 60° F., and, if after the entrance of steam for some time, its temperature has been raised to 212°, the steam has supplied 152 calories of heat to the water in the vessel. It is now necessary to determine how much steam was necessary to supply 152 calories of heat. This may be determined by weighing the water as soon as its temperature has arrived at 212° and subtracting from this the weight of the water at the beginning of the experiment. The additional weight is evidently due to the addition of that part of the steam which was condensed on entering the vessel.

If the weight of the water added to the vessel be .156+ of a pound, it is evident that .156+ of a pound of steam was able to raise the temperature of 1 pound of water from 60° F. to 212° F. Therefore, .156+ of a pound of steam gives up 152 calories of heat on changing from steam at

212° to water at 212°. It must, consequently, have required 152 calories of heat to convert .156+ of a pound of water, at a temperature of 212°, to steam at 212°.

From this it may be calculated that it would have required about 965 calories of heat to convert an entire pound of water, at 212°, to steam at 212°.

In raising one pound of water from ice at a temperature of 0° to steam at a temperature of 250°, 1321.3 calories are needed. Of these only 214.3 calories are used in raising the temperature. The remainder are utilized in changing the ice to water and the water to steam. In the diagram (Fig. 65) the number of calories needed to raise the temperature is indicated by the length of the

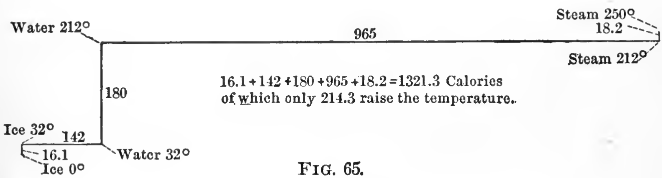


FIG. 65.

vertical lines and the number needed to change ice to water, and water to steam, by the length of the horizontal lines.

110. Latent Heat of Water and Steam.—When the changes of ice to water, and of water to steam were first studied, observers merely noticed that the mercury in the thermometers failed to rise during the time in which these changes were taking place, while at other times any addition of heat was at once followed by a rise in temperature. Observers, therefore, said that during the change of a substance from a solid to a liquid state, and later again during the change from a liquid to a gaseous state, a definite quantity of heat in some way became hidden.

The heat which disappeared while these changes were taking place was called *latent heat*, the word "latent" meaning to lie hidden or concealed. Such expressions as the latent heat of water and the latent heat of steam are still in common use. In the preceding paragraphs it has been shown that the latent heat of water is equal to 142 calories, and the latent heat of steam to 965 calories.

When steam returns to water, or water to ice, the latent heat is again given out.

111. Importance of the Large Latent Heat of Water.—Every pound of water, on changing from water at a temperature of 32° to ice at 32° F., must give out 142 calories of heat. This quantity of heat must escape before the next pound of water can turn into ice.

When the water at the surface of a lake or river freezes, it not only gives out heat to the air above but also to the water below. This causes the freezing of lakes and rivers to be very slow. Therefore, the depth to which water is frozen is very slight compared to the depth to which it would be frozen, if the heat which it gave out on changing from a liquid to a solid state were very small.

During very cold weather, when the vegetables in the cellar are in danger of freezing, some people, in order to prevent serious injury, place a tub of water near the vegetables. Every pound of water which freezes gives out 142 calories of heat. This heat becomes dispersed throughout the cellar, and the total quantity of heat given out is often sufficient to prevent serious injury to the vegetables. Fortunately, most winter vegetables do not suffer from cold until a temperature of several degrees below the freezing point has been reached.

When ice is melted in the laboratory, the heat necessary

to change ice into water is supplied by a Bunsen burner or some other artificial source of heat. In this case the source of heat is evident. However when ice melts on exposure to the open air, without any especial attempt being made to supply heat to the ice, the fact that it requires a considerable quantity of heat to melt every pound of ice is likely to be overlooked. From what source is this heat obtained? From the surrounding objects.

The fact that ice, in order to melt, withdraws heat from surrounding objects may be shown in a number of ways. The ice in an ice-chest, on melting, withdraws heat from the objects placed in the chest. When snow melts in the early spring, the air frequently feels very chilly. So much heat is withdrawn from surrounding objects, including both the air and the snow in the immediate neighborhood, as to prevent the rapid melting of the snow. If it were not for this fact, disastrous floods, similar to those which are often caused at present by thaws which follow a considerable fall of snow, would be far more extensive and frequent. Near Lake Erie, spring is often so much retarded by the melting of the winter's ice and snow, that the buds of trees usually do not begin growth until the danger of late frost is past.

112. Importance of the Large Latent Heat of Steam.—The fact, that it requires 965 calories of heat to convert one pound of water into steam, makes necessary the consumption of enormous quantities of coal for the production of steam in boilers. The heat which is given out, when steam returns to the liquid condition, is utilized in the heating of buildings. Every pound of steam which condenses to water inside of a radiator, used for heating, supplies 965 calories of heat to the room. As the condensed water returns to the boiler, it continues to give

out heat, in consequence of the water falling to a temperature below 212°.

113. Heat Withdrawn by the Evaporation of Liquids.—When water is converted into vapor by means of ordinary evaporation, heat is consumed in the same manner as when water is converted into steam, but the process is much slower. The heat which is used to convert the water to vapor is withdrawn from surrounding objects. After a shower of rain the water evaporates and cools the air by withdrawing from the air a portion of its heat. The evaporation of water, sprinkled on the floor, cools the air of a warm room. The evaporation of perspiration during a hot day serves to cool the body. When the air is already saturated with moisture, so that the perspiration fails to evaporate promptly, much discomfort is felt. Fanning causes a more rapid evaporation of the perspiration, and thereby produces a refreshing coolness. In tropical countries water is cooled by being placed in porous jars set in a draught of air. A small quantity of water passes through the pores of the jar, and, on evaporating, withdraws so much heat from the jar that the temperature of the water remaining in the jar is lowered considerably below that of water contained in any vessel which does not permit ready evaporation.

Ether, when thrown in a fine spray, evaporates so rapidly and withdraws such great quantities of heat from surrounding objects that, when thrown on any part of the body this part becomes numb on account of the cold. In this manner, parts of the body are rendered insensible to pain during surgical operations.

114. Cold Produced by Solution.—When a substance dissolves, it turns from a solid into what may be considered a liquid form. It requires heat to enable it to make this

change of state. The necessary heat is withdrawn from surrounding objects, the chief of which is the liquid in which the substance dissolves.

If a certain quantity of the solid, called ammonium nitrate, is thrown into an equal weight of water, the solid dissolves and the temperature of the water falls about 45° F. If four parts, by weight, of crystallized chloride of calcium are mingled with three parts of snow, both the chloride of calcium and the snow become liquefied and the temperature of the mixture falls about 86°. If one part, by weight, of salt be mixed with two parts of finely broken ice, both are liquefied, and if care is taken to exclude the surrounding heat, the temperature is lowered nearly 38°. The salt causes the ice to melt more rapidly than the ice would melt if the salt were not present. The result is that a much greater degree of cold is produced than would be the case if the ice were melted alone. For this reason the cream in an ice-cream freezer is surrounded by a mixture of ice and salt. Even if salt alone were placed in water the temperature of the water would be lowered to a perceptible extent (§ 193).

115. Gases Cool as they Expand.—A gas can be caused to expand by increasing the quantity of heat which it contains. This may be accomplished by means of a Bunsen burner or some other source of heat. It requires heat to cause molecules to move apart. If a gas is allowed to expand, by reducing the pressure which is exerted upon it, the heat must be secured from some other source. This source of heat is the gas itself together with all the objects enclosed within and surrounding the gas. Therefore, when a gas expands the temperature of the gas is found to decrease.

This principle is illustrated in the formation of clouds.

Air can absorb a certain quantity of moisture. This quantity increases with the temperature of the air. When air is heated it rises (§ 127). As it ascends to higher elevations, the heated air is subjected to less pressure from the atmosphere. It therefore expands, and, in order to expand, heat is necessary. This heat is secured from the air and the moisture which it contains. In consequence, the temperature of the air falls. When air cools, it can no longer hold as much moisture. A part of the moisture, therefore, leaves the air and collects in minute drops. If the number of these drops is large, they may be seen some distance above the earth in the form of a cloud. The drops of water are so small and so light that they seem to remain suspended in the air at nearly the same levels. In reality, however, they settle slowly through the air, but on reaching the warmer air below are reabsorbed again, so that the falling of the little drops of moisture which form clouds does not attract attention.

116. Capacity of Different Substances for Heat.—Some substances have a greater capacity for heat than others. For instance, the same amount of heat which will raise one pound of water one degree would be sufficient to raise the temperature of 33 pounds of lead one degree. In other words, water has 33 times more capacity for heat than lead. Copper has about three times as much capacity for heat as lead. Iron has nearly four times as much. On account of the great capacity of water for heat, water is taken as the standard with which the capacity of other substances is compared.

117. The Irregular Expansion of Water.—As a rule, any increase in the quantity of heat contained in any substance causes it to expand. This rule applies not only to

substances while in the solid, liquid, or gaseous condition, but also to substances while changing from a solid to a liquid, or from a liquid to a gaseous state.

Water is one of the most striking exceptions to this rule. When water changes from the solid to the liquid state, it contracts. In the liquid state it occupies only .917 of the volume occupied by the ice just before melting. The result is that ice floats in water.

Most liquids expand on being heated from the melting to the boiling point. They do not expand equally for every equal increase of temperature, but they at least expand.

Water, on the contrary, at first contracts and then expands. From 32° it contracts until a temperature of 39.2° is reached; from 39.2° to 212° it expands. The rate of contraction and of expansion is unequal. From 32° to 39.2° the rate of contraction decreases until at 39.2° F. the rate of contraction is very slight. Above 39.2° the rate of expansion is at first very slight and then increases until the boiling point is reached. At 200° F., for instance, an increase in temperature of 1° F. causes an increase in volume six times as great as a corresponding increase of temperature at 50°.

The total decrease of volume between 32° and 39.2° F. is only $\frac{1}{10,000}$ of the original volume. The total increase of volume on raising water from a temperature of 39.2° to that of 212° F., is about $\frac{1}{23}$ of its volume at 39.2° F. Ice, therefore, floats in water at any temperature.

118. Heat Produced by Collision.—Place a small piece of iron on an anvil and pound it vigorously with a hammer. It soon becomes warm, and, if it be pounded for a sufficient length of time, it will become too hot to be held in the hand.

Pounding causes the molecules at the surface of the iron to move violently. The molecules at the surface strike the molecules just beneath and set these also in motion. Molecules strike against molecules, rebound, and strike against other molecules, until, finally, all the molecules within the body take part in the motion. In the meantime, if the pounding be kept up, the heat of the piece of iron continually increases.

119. Heat Produced by Compression and Friction.—When a bullet is fired against a stone, the lead of which the bullet is composed is violently compressed and becomes hot. As the lead is stopped by the stone, the concussion is sufficient to set the molecules of lead into violent motion. Increase of heat is the result.

A sudden compression of air will also produce heat. Attach a small piece of dry tinder to the end of a piston fitting air-tight in the cylinder of a fire syringe, and plunge the piston quickly into the cylinder (Fig. 66). During the compression of the air within the cylinder, the molecules of air are set in motion and this generates sufficient heat to ignite the tinder.

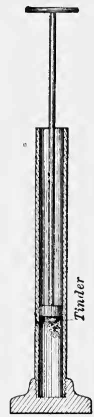


FIG. 66.

Hold a piece of iron against the edge of a dry, rapidly revolving grindstone. The grindstone knocks off tiny fragments of the iron. These fragments are so heated as a result of the concussion that, as they fly off, they produce the appearance of a stream of sparks.

Rub the knuckles vigorously back and forth on the sleeve of your coat. The friction of the knuckles against the sleeve sets the molecules in violent motion and the knuckles become hot. Indians start fires by rapidly whirling the end of a soft piece of wood in the hollow

formed on the upper surface of a harder piece. The friction produces enough heat to set the softer wood on fire.

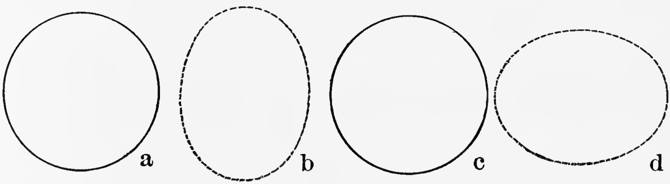
120. Heat a Form of Molecular Motion.—Collision, compression, and friction, all cause molecular motion, and all result in an increase of heat. This suggests that heat is the result of molecular motion, and that increase in molecular motion results in an increase of heat. When the temperature of a body is increased, the molecules are set in more violent motion. They strike each other with such force that they knock each other farther apart, and, in consequence, the body expands. When a body cools, the motion of its molecules becomes less violent, the molecules do not knock each other so far apart, and the volume of the body decreases (§§ 61, 62, and 63).

The nature of these molecular motions is not fully understood. The motions so far described partake chiefly of the nature of a bombardment. The molecules move in one direction until they come into violent contact with other molecules, when they rebound and move in some other direction. This form of motion from place to place may be called a motion of *translation.*

When one molecule strikes against another molecule, there is also another form of motion in addition to the motion of translation. The molecule struck apparently is caused to tremble. Since we do not exactly know what a molecule is, or what form it possesses, we do not have a very exact idea as to the nature of the trembling which takes place in the material of a molecule after it has been struck. But we may get some conception of such a motion by studying the motions of a very elastic rubber ball.

When a rubber ball (Fig. 67, a) is struck violently it flattens for a moment transversely to the direction of the blow (b). Then the displaced particles return so

violently to their original positions that they do not cease their motion when the ball has resumed its original shape, but for a moment the particles, which were moving outward, continue to move outward, and those which were moving inward continue to move inward. The result is that the flattened ball first returns to its original shape (c) and then assumes the form of a slightly elongated football (d). Then the particles which have been moving outward, return, and those which have been moving inward, move outward; until the flattened



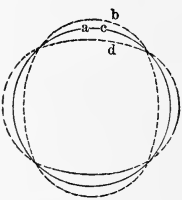


FIG. 67.

condition, assumed at first (b), is resumed. This action continues for some time, becoming less violent if no further concussions occur, until the motion finally ceases. This is one of the many possible forms of *vibration*. The concussion of molecules against each other may give to them a vibratory motion somewhat of this character.

The motions which cause the molecular phenomena called heat are, probably, a combination of the motions of vibration and translation, and possibly also of other forms of motion, such as rotation.

121. Conduction.—Place one end of a very short bar of iron on an anvil and pound this end vigorously with a hammer. Not only will the end which was pounded

become hot, but, if the pounding is continued long enough, the opposite end, which was not struck, will also become distinctly warmer. The violent motions of the molecules struck by the hammer are communicated from molecule to molecule until even the molecules at the extreme end of the bar of iron are set in violent motion.

Hold in your hand one end of an iron rod about eight inches long, and place the other end in the flame of a Bunsen burner. The end held in the hand also becomes hot. The molecules brought into contact with the flame are caused to move violently on account of the heat, and this motion is communicated from molecule to molecule until the molecules at the end held in the hand also move violently.

In the case just described, both the bar and the rod maintain their general form, showing that while these molecules are in motion they do not change their *relative* positions. If there were any considerable change in the relative positions of the molecules, the general form of the bar and rod could not be maintained. The communication of heat from one part of a body to another caused by communication of motion from molecule to molecule, not accompanied by any change in the relative positions of the molecules, is called *conduction.*

122. Relative Conductivity of Different Solids.—As a rule the metals are the best conductors of heat. But different metals vary greatly in the rapidity with which they conduct heat. Copper conducts heat about four times as effectively as iron. Rocks are much poorer conductors of heat. The conductivity of sandstone, for instance, is only one-twentieth of that of iron. The various kinds of wood are still poorer conductors. The wood of the fir-tree, for example, conducts heat only $\frac{1}{500}$ as readily as iron.

The temperature of the human body is 98.5° F. If on a cold winter morning, when the temperature of the air in a room and of all the objects within the room is about 32° F., a person should step with bare feet in succession on a piece of iron, a piece of wood, and the carpet, the iron would feel colder than the wood, and the wood would feel colder than the carpet. Iron conducts the heat away from the foot more rapidly than wood, and wood conducts the heat away more rapidly than the woollen carpet. In consequence, the temperature of the foot is lowered much more rapidly when in contact with the iron than when in contact with the carpet. Therefore the iron feels colder, although its temperature is practically the same as that of the carpet.

Clothing for summer use should be made of material which conducts heat away from the body fairly well. Linen and cotton are the best materials in common use. During the winter, clothing should be made of the poorest conductors of heat. Wool is one of the best non-conductors in common use. Furs are used extensively in northern countries. The feathers and down of northern birds are such effective non-conductors that in some countries they are sewn up in ticks and in this form are used in the place of quilts as a covering for beds during the winter months. The non-conductivity of loose wool, furs, and feathers is largely due to the air imprisoned between the fibres or hairs forming the material.

Paper is a good non-conductor. In early spring, and late fall, plants may be protected by covering them with paper. If, on a very cold night, several layers of ordinary newspaper be placed between the quilts on a bed, the warmth of the body will be better kept up. Several newspapers wrapped around the body, underneath a

coat, will serve as a very effective protection against the cold in stormy winter weather.

123. Heating of Glass Vessels.—All varieties of glass are poor conductors of heat. If hot water is poured into a thick glass vessel having the ordinary temperature of the room, the interior begins to expand strongly before the heat has been conducted to the outer surface, and, in consequence, the vessel often cracks. For similar reasons a thick glass vessel is likely to crack if heat is suddenly applied to the exterior by means of a Bunsen burner. In order to avoid cracking on account of unequal expansion, glass vessels used for chemical experiments requiring heat are usually made of thin glass.

Even thin glass vessels require the use of certain precautions to avoid cracking. The greatest heat should not be applied to the end of the test-tube, since this part of the tube is often thinner than the sides. Apply the heat gradually, moving the test-tube in and out of the flame, and rolling it slightly between thumb and finger. Beakers and flasks may easily become unequally heated and crack. In order to avoid this, place the beaker on a piece of brass wire-gauze (Figs. 64, 71) supported by a ring stand. Brass conducts heat 150 times better than glass. Hence the brass wire-gauze will conduct the heat so rapidly to all parts of the base of the beaker or flask, that the base of the beaker is more equally heated and the risk of breaking it is very much lessened. But even in this case the heat should be applied gradually at first.

Do not apply heat to that part of a test-tube which is on a level with the top of the liquid inside. The dry glass is likely to become so much warmer than that which is kept cooler by contact with the liquid that the tube may crack. For similar reasons do not place in the di-

rect flame any test-tube to whose walls the drops of any liquid adhere.

124. Liquids Poor Conductors of Heat.—The fact that liquids are not good conductors of heat can be shown in quite a number of ways. In northern countries large fires are often built on the ice of rivers and ponds, to furnish light and heat to skaters. As soon as a thin layer of water is formed beneath the burning wood, the ice almost ceases to melt. If a metal pan is floated upon water (Fig. 68), and alcohol is placed in the pan and set on fire, the metal pan communicates the heat quickly to the water, but the lower part of the water remains cold for a very long time.

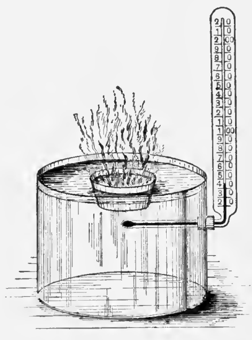


FIG. 68.

If the flame of a Bunsen burner is directed against the upper part of a test tube nearly full of water (Fig. 69), the upper part of the water may be made to boil while the water in the lower part of the tube remains quite cool.

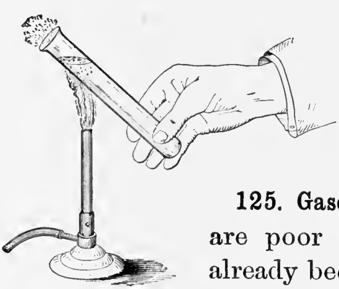


FIG. 69.

125. Gases are Poor Conductors.—Gases are poor conductors of heat. It has already been mentioned that the air enclosed in loose wool, furs, and feathers, contributes much toward the non-conductivity of these substances. The air enclosed between double doors and windows also serves as a non-conductor, and prevents the escape of heat from houses. The air enclosed between particles of sawdust placed within the

walls of ice-houses is an important factor, during the summer, in preventing the heat outside of the ice-house from gaining entrance to the ice within (§§ 217–223).

126. Convection of Liquids.—Notwithstanding the fact that liquids are poor conductors, heat is often readily communicated from one part of the liquid in a vessel to another part in the same vessel. If a Bunsen burner be placed beneath a test-tube, inclined at a moderate angle, the water at the base of the tube becomes hot (Fig. 70). It expands, becomes lighter, and, in consequence, it rises along the upper side of the inclined tube and floats on top of the water not yet heated. At the same time the water, which is at a greater distance above the flame, and which is still cold, comes down along the lower side of the inclined tube, and takes the place of the water which is rising. This colder water becomes heated in its turn and also rises. The result is the formation of a continuous current which can be easily recognized if fine cork-dust is thrown into the water. In the same manner, irregular currents are started in the water in tea-kettles, or in coffee-pots, when placed over a fire (Fig. 71).

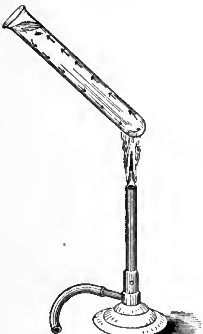


FIG. 70.

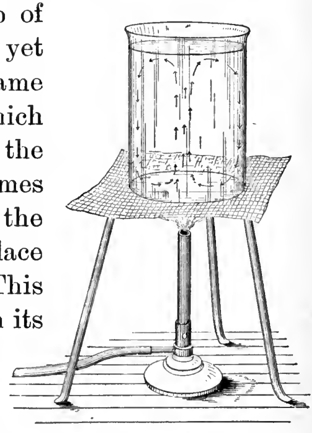


FIG. 71.

In all of these cases the heated water expands and becomes lighter. The colder water is heavier. Both kinds

of water are pulled down by the attractive force of the earth (gravitation). Since the heavier water is pulled down with greater force, the heavier water will be drawn beneath the lighter water, and the lighter water in consequence will then rise to the top.

The water at the surface of the ocean within the tropics becomes much more heated than that at the surface within the Arctic regions. In consequence, the colder water of the Arctic ocean gradually and very slowly settles beneath the warmer water of more southern regions, while the heated water of the Torrid zone gradually passes northward along the surface until it reaches the Arctic Ocean. This is one of the causes which produce currents in the ocean.

127. Convection of Gases. — When air is unequally heated, so that one part of the air becomes hot while the other remains cold, the hot air becomes lighter than the cold air. The cold air therefore crowds downward and takes the place of the warmer air. Currents are produced in the air similar to those produced in water, and, as a result of the currents, the entire air finally becomes heated.

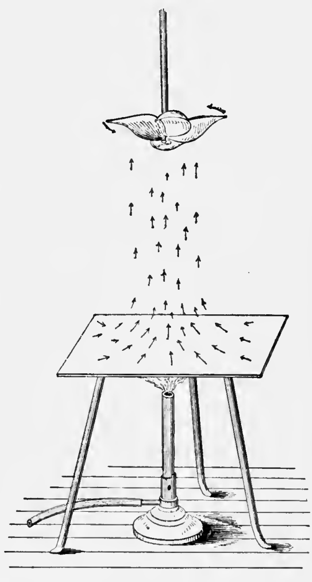


Fig. 72.

Place a piece of sheet-iron on a ring stand over a Bunsen burner (Fig. 72). Hold a paper pin-wheel over the sheet-iron. The ascending hot air causes the wheel to rotate. If convenient, hold the same

wheel near the side of a stove-pipe and notice the same result, caused in this case by the ascending currents of heated air along the sides of the heated stove-pipe.

If the door connecting a warm room with a cold one is opened slightly, and a lighted candle is held at the base, the coming in of the cold air is readily detected by the fact that the flame is blown inward. If the candle is held near the top of the door, the flame is blown outward, showing that the cold air is passing beneath the warm air, and that warm air is rising above the cold air.

In order to ventilate a room during winter weather without too great a loss of heat, the lower part of the window should be raised. In order to cool the room as rapidly as possible, the upper window should be lowered.

When fire is placed in a stove, the colder, heavier air in the room pushes the much warmer and lighter air in the stove up the chimney. The heated air is not drawn up the chimney from above as is often supposed, but is forced up by the weight of the colder air surrounding it.

128. Convection Due to Displacement of Molecules.—Heat is conveyed to the more remote parts of liquids and gases by means of currents. The molecules in contact with the source of heat are set in violent vibration. The heated molecules are continually pushed aside, and give the cooler molecules an opportunity to become heated in their turn. The final result is that all the molecules become heated. The transference of heat through liquids and gases, by means of a circulation among the molecules, is called *convection*.

Why the molecules of liquids and gases are not able to communicate their vibrations readily from molecule to molecule, as is the case with many solids, is unknown.

The result, however, is that the transference of heat in liquids and gases is dependent upon currents.

129. Sensation of Heat and Cold cannot be Relied upon to Determine Temperature.—Although the body is usually able to distinguish between heat and cold, it is not always a safe guide. Take three basins, the first containing ice-water, the second, lukewarm water, and the third, water as hot as can be endured without injury. Place the left hand in the ice-water and the right hand in the hot water. As soon as the hands have grown somewhat accustomed to the temperatures in the two basins, plunge both hands at the same time into the lukewarm water. The left hand now feels warm, while the right hand feels cool. In fact, the left hand feels warmer than the right hand, notwithstanding the fact that both hands are in the same basin.

During winter weather, persons coming into a room from the very cold air of the street, often call the air in the room hot and close. A person working vigorously in the same room may also consider the air too warm. Nevertheless a thermometer hanging on the wall may register a temperature of only 68°, and most of the persons seated in the room may consider the air a trifle cool. A thermometer is the only safe guide for determining the actual temperature of a room. We cannot rely altogether upon our senses.

130. The Sensations of Temperature, Pain, and Touch.—It is commonly stated that man has five senses: seeing, hearing, tasting, smelling, and feeling. The result of recent investigations, however, indicates that a number of distinct sensations have been usually classed together under the heading, *feeling*. Among these are the sensations of touch, temperature, and pain.

Investigations indicate that there are as many kinds of nerves as there are sensations; that each kind of nerves is so constituted as to be particularly sensitive toward some special form of irritation. Thus, the nerves of sight, if irritated by a pin, are not aroused to a true sensation of touch or pain.

Each kind of nerve terminates at some special part of the body. Thus, the nerves of sight terminate in the eye; those of hearing, in the ear; of taste, in various parts of the mouth; of smell, in the nose. No attempt was made formerly to distinguish carefully between the areas in which the nerves of touch, temperature, or pain terminate. In consequence no distinction was discovered between these three different kinds of nerves. They were classed together as nerves of feeling, and it was believed that any part of the skin capable of feeling one of these sensations was also capable of feeling the other two.

However, it is now known that in certain diseases of the spinal cord areas of skin may be mapped out in which the sensation of pressure (touch) is lost, while that of temperature remains; areas may also be found in which the sensation of temperature is lost and that of pressure remains. Sometimes, in cases of persons under surgical treatment, before the patient comes fully under the influence of ether or of chloroform, the sensation of touch remains, while that of pain is lost. In each of these cases, the facts indicate that one class of nerves has lost its power to receive sensations, while the other class of nerves mentioned still remains active.

Recent investigations indicate that there are two sets of nerves of temperature: one to indicate warmth, the other to indicate cold. In some diseases the patient can appreciate warmth applied to the skin but not cold. The

areas of the skin in which the sensation of heat is perceptible, and the areas in which the sensation of cold can be felt, have been carefully mapped out on various parts of the surface of the body, and the discovery has been made, that these areas are often distinct, although sometimes they overlap. These areas appear to be the places where the nerves capable of perceiving a rise of temperature, and those capable of perceiving a fall of temperature, terminate. Since the sensations of heat and cold are often localized in different areas, it seems reasonable to conclude that the sensations are felt by different nerves.

By a similar method of investigation it has been determined that there are special nerves to convey the sensation of pain.

131. Extremes of Temperature.—By means of the electric furnace, M. Moissan, of Paris, has secured temperatures as high as 6,000 to 7,000 degrees Fahrenheit. The temperature of the sun is considerably greater. Widely different estimates have been made. Probably 16,000 to 18,000 degrees Fahrenheit is near the truth. Owing to the scattering of the heat as it spreads away from the sun, only one two-billionth of the total quantity of heat given out by the sun ever reaches the earth. The remainder passes to other points in space.

When liquid air is allowed to evaporate, temperatures of about 312 degrees below zero, Fahrenheit, are produced. By allowing solid hydrogen to liquefy and then to evaporate, Professor Dewar, of London, has succeeded in getting temperatures as low as 432 degrees below zero. Theoretically, the lowest temperature which it will ever be possible to secure is 460 degrees below zero, Fahrenheit. It is unknown whether there is any upper limit to temperature.

CHAPTER IV

CHEMISTRY, ATOMS

132. Principles Underlying Recognition of Gases.—Gases play a very important part in many chemical phenomena. Therefore, the ability to recognize gases is of the highest importance. Some gases may be distinguished with some exactness by their color, or by their peculiar odor. But many gases are both colorless and odorless, and their recognition depends upon a clear understanding of their chemical properties. Among the most important of these colorless gases are oxygen, hydrogen, carbon dioxide, and nitrogen.

The action of these gases has been studied under many kinds of chemical influences, and the action of each gas under each of these influences is fully known. By a comparison of the results obtained, it has been determined which actions or combinations of actions are characteristic of each particular gas, and which therefore can be used as a means of identification. Several of the important characteristics of oxygen, hydrogen, carbon dioxide, and nitrogen are given in the following paragraphs.

133. Pneumatic Trough. — Procure a galvanized iron trough (Fig. 73) constructed in accordance with the following directions:—

Height, 8 inches. Width, 10 inches. Length, 18 inches. Edges along the top strengthened by turning them over a strong wire. A handle at each end of the trough for

convenience in lifting. Four holes, $\frac{3}{8}$ of an inch in diameter, near the upper edge of the trough; each hole 3 inches from the nearest corner, the lower edge of the hole not more than one inch below the top of the trough.

Across the centre of the trough, a permanent shelf, also of galvanized iron, strengthened by turning the edges over strong iron wire; this shelf, 8 inches wide, so supported as to be 2 inches below the top of the trough; in this shelf, four holes $\frac{3}{8}$ of an inch in diameter, each

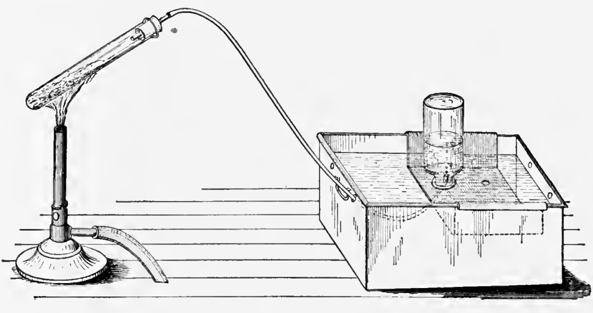


FIG. 73.

hole 2 inches from the edge of the shelf and 2.5 inches from the side of the trough.

Fill the trough with water. Lower a fruit-jar into the water, and allow the water to rush in and fill the jar completely, so that no air remains in the jar. This can be done easily if jars of proper size and form are selected. Invert the jar in the water, raise it, and place it over one of the holes in the shelf. If the mouth of the jar be kept below the surface of the water, none of the water will escape. It is held up by the pressure of the air. On this account the trough is usually called a *pneumatic trough.*

Instead of the pneumatic trough here described, a pan

or basin may be used. Fill the jar with water, cover it with a piece of wet pasteboard, invert it, place its mouth beneath the level of the water in the basin, remove the pasteboard and support the jar on a piece of the hoop of a bucket bent into the form of a letter V placed horizontally. Insert the end of the delivery tube (§ 134) beneath the mouth of the jar.

134. Method of Securing Oxygen.—Crush four ounces of potassium chlorate in a mortar, until it is about as coarse as granulated sugar. Mix it thoroughly with four ounces of manganese dioxide. Place in a test-tube enough of this mixture to fill one-third of the tube (Fig. 73). Close the top of the tube with a one-hole rubber stopper. Through the hole insert a glass tube, and over the glass tube, slip one end of a piece of rubber tubing about 30 inches long. Thrust the free end of this rubber tube through the nearest opening in the side of the trough and, leading it through the water, push it up through that hole in the shelf which is directly beneath the mouth of an inverted jar filled with water. The friction between the rubber tubing and the rough sides of the opening is sufficient to hold the tubing in place.

Hold the test-tube in an inclined position, and heat it by means of a Bunsen burner. At first apply a moderate amount of heat to the upper part of the powder, shifting the flame of the burner back and forth, so as not to injure the test-tube by overheating a small part of the glass while the rest of the tube is still comparatively cold. Increase the heat gradually until gas is given off freely, but not with such rapidity as to visibly disturb the powder. If the gas is given off too rapidly, hold the Bunsen burner at a greater distance. As the supply of gas given off by the upper part of the powder begins to lessen, apply the

heat to the lower part of the tube. Toward the end of the experiment it will be necessary to increase the amount of heat considerably in order to keep up the free flow of the gas. This gas will flow through the rubber tube and will escape into the water just within the mouth of the jar on the shelf in the pneumatic trough. Do not collect the gas until it bubbles freely through the water. The rubber tube used to convey the gas is called the *delivery tube.*

As the gas escapes from the tube, bubbles of the gas rise to the top of the inverted jar and collect there in such quantities that they push the water toward the lower part of the jar. As the gas accumulates, less and less water is left in the jar. Finally gas fills the entire jar and begins to escape at the bottom. Now move the jar to some other part of the shelf, keeping the mouth of the jar below the surface of the water. Prepare a fresh jar for the collection of an additional supply of gas. Jars filled with oxygen may be removed without losing any of the gas by covering the mouth of the jar with wet filter-paper or a wet blotter before lifting it out.

As soon as the flame of the Bunsen burner is removed, the gas within the test-tube cools, shrinks in volume, and tends to form a vacuum. The pressure of the outside air is then likely to force cold water through the delivery tube into the hot test-tube. This almost invariably cracks the test-tube. Therefore, the delivery tube should always be removed from the pneumatic trough *before* removing the test-tube from the flame of the Bunsen burner.

135. Properties of Oxygen.—Oxygen is slightly heavier than air. It may therefore be kept in bottles which are not inverted, provided the mouths are covered with wet filter-paper. When retained in an inverted bottle, the

mouth must dip into water, the latter serving as a stopper.

Set fire to a long splinter of wood. Blow out the flame and, while the end of the splinter is still glowing, thrust it down into a jar filled with oxygen. The glowing tip will burst into flame. Repeat the operation until the supply of oxygen is exhausted. Oxygen supports combustion. Heat the unwound end of a stranded iron picture-wire red hot, dip it into powdered sulphur, and, while the sulphur is still burning, lower the wire into the jar filled with oxygen (Fig. 74). The iron burns with brilliant scintillations. Drops of a black melted substance fall to the bottom and often crack the jar, unless the bottom of the jar is covered by at least an inch in depth of water. A piece of pasteboard held over the top of the jar while the burning is taking place, will prevent the too ready escape of the gas.

FIG. 74.

If a burning match is brought in contact with the oxygen at the mouth of the jar, where the gas comes in contact with the air, the oxygen does not burn, although the match burns more brightly. Mixed with air, it does not explode. When oxygen is mingled with lime-water, the lime-water remains colorless and transparent.

136. Oxygen is Present in Ordinary Air.—The glowing tip of a splinter of wood will not burst into flame on being held quietly in air, but it may be caused to burst into flame by bringing it in contact with *more* air, either by waving the splinter through the air, or by blowing air against the glowing end of the splinter. In other words, air acts as though it contained oxygen diluted with considerable quantities of some other gas which does not support combustion.

137. Method of Securing Hydrogen.—Introduce into a two-necked Woulfe bottle sufficient granulated zinc, or sheet zinc cut into small pieces, to form a layer at least half an inch deep (Fig. 75). Pour in water enough to raise the water level about half an inch above the zinc. In one of the necks of the bottle place a rubber stopper, and through the hole in the stopper thrust a thistle-tube until the bottom of the tube is below the surface of the water. In the second neck of the bottle place another rubber stopper. Through the hole in this stopper thrust one end of a bent glass tube; to the other end of this tube attach the delivery tube. Fill with water two jars on the shelf of the pneumatic trough, as in the preceding experiment, and introduce the open end of the delivery tube into the mouth of one of these jars.

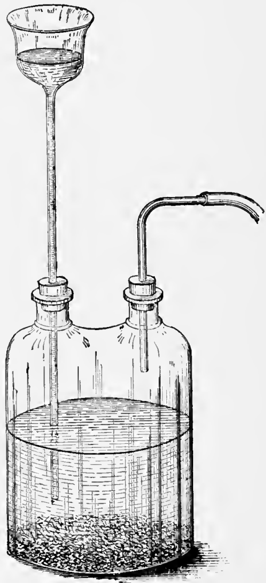


FIG. 75.

Pour into the thistle-tube a mixture of one part of hydrochloric acid and three parts of water. Hydrogen is given off at the place of contact between the acid and the zinc. As this hydrogen passes over into the jar, it carries with it the air which is in the Woulfe bottle. The first jar of gas collected is a mixture of hydrogen and air. Since a mixture of hydrogen and air explodes violently when set on fire, the first jar of gas collected should be thrown away as soon as the collecting of gas in the second jar has been started. Of course, heat should *not* be applied at any time to the Woulfe bottle, nor should any flame, large or small,

be allowed in the vicinity of the apparatus while the collecting of gases is going on.

In order to ascertain whether the hydrogen is pure, before the collecting of gas in the second jar is begun, collect a test-tube full of the gas in the same manner as in the case of the jars. Raise the test-tube from the water, being careful to retain its inverted position, and light the gas quickly at the mouth of the tube. If the gas burns quietly and without any explosion, it is pure. Since there is only a small quantity of gas in the test-tube, the test is not dangerous even if the hydrogen is still mixed with air.

As soon as the production of gas becomes slow, more hydrochloric acid should be added. In adding the acid, never fill more than half of the bowl of the thistle-tube; otherwise any unexpectedly rapid production of gas may produce such a great pressure within the bottle, that a part of the acid may be pushed out of the top of the thistle-tube.

138. Properties of Hydrogen.—Place a bottle containing hydrogen in an upright position and remove the paper or glass covering the mouth, for three minutes—by the clock. Drop a lighted match into the jar. Why has the gas escaped?

Hydrogen weighs $\frac{1}{14}$ as much as air. Therefore in the following experiments the jars or test-tubes containing the hydrogen should be held in a vertical position, mouth downward.

If a burning splinter of wood is thrust up into an inverted jar filled with hydrogen, the flame is extinguished by the hydrogen (Fig. 76). Hydrogen does not support combustion. However, the gas itself is set on fire where it comes in contact with the air, at the open mouth of the

jar. The oxygen in the air supports the combustion of the hydrogen. When hydrogen is mingled with lime-water, the lime-water remains colorless and transparent.

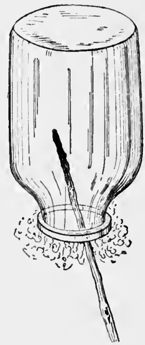


FIG. 76.

If the hydrogen in the jar is thoroughly mixed with air, the hydrogen in all parts of the jar can burn at the same time, and if it is set on fire, it burns so rapidly and vigorously that violent explosion results. On this account it is safer not to use a fruit-jar full of hydrogen for these experiments. A large test-tube filled with hydrogen is sufficient for most experiments.

139. Method of Securing Carbon Dioxide.—In a two-necked Woulfe bottle (Fig. 75) place about one-third of a tumblerful of marble or of limestone broken into small lumps. Pour in water enough to cover the bottom of the bottle. Insert a thistle-tube, connect the delivery tube, and arrange for the escape of gas into the jars on the shelf of the pneumatic trough, as in the preceding experiments. Then pour in concentrated hydrochloric acid enough to cover the marble. In order to secure carbon dioxide unmixed with air, throw away the first jarful of gas collected.

Since carbon dioxide is considerably heavier than air, it may be collected without the use of the pneumatic trough. Through the mouth of an erect, empty jar thrust the open end of the delivery tube, so that the gas will escape into the jar at the bottom. The air in the jar will be gradually pushed out by the entering gas. The flow of the gas should be allowed to continue for some time, in order to be certain that the last remnant of air has been removed from the jar. In order to retain the gas, the jar should

be covered with a piece of wet filter-paper or window glass.

At the ordinary pressure of the air, water absorbs its own volume of carbon dioxide. If it be desirable to retain for any length of time the gas collected in the jar over the pneumatic trough, slip a piece of ordinary window glass under the mouth of the jar, and set the jar aside in an erect position.

140. Properties of Carbon Dioxide.—Since carbon dioxide weighs $1\frac{1}{2}$ times as much as air, the jar containing this gas should be placed in an erect position. If a burning

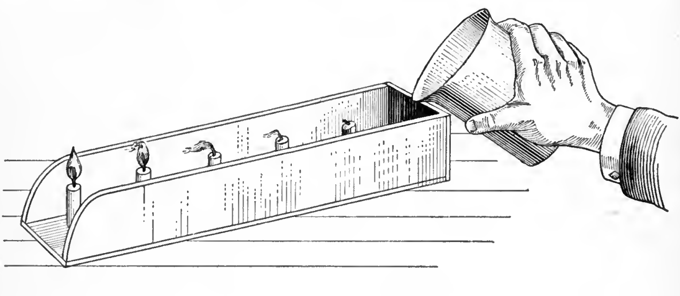


FIG. 77.

splinter of wood is thrust down into a jar filled with carbon dioxide, the flame is extinguished, and the carbon dioxide does not ignite at the mouth of the jar, where it comes in contact with the air. It does not explode when mingled with air.

Pour carbon dioxide down a slanting wooden trough, along which is arranged a row of short, lighted candles (Fig. 77). The candles are extinguished in succession, as soon as they are covered by the downward-flowing but invisible gas.

Pour water into a fruit-jar containing carbon dioxide

until it is one-third full of water. Close the jar air-tight, shake it vigorously, and open it again under water, mouth downward. A large part of the carbon dioxide has disappeared. It has been taken up or dissolved by the water.

When the gas is allowed to flow for a short time through lime-water, the lime-water assumes a milky appearance. The same effect may be produced by pouring a small quantity of lime-water into a jar containing carbon dioxide and shaking the jar violently. In consequence of the shaking the gas and the lime-water become intermingled.

In order to prepare lime-water, place a small lump of quick-lime, such as is used by plasterers and masons, in a jar full of water. Allow the jar to stand over night, then pour off the clear liquid and, if it is not perfectly clear, filter it.

141. Carbon Dioxide Present in Ordinary Air and in the Breath.—Place lime-water in a bottle closed with a rubber stopper provided with two openings (Fig. 78). Through one opening thrust a glass tube beneath the surface of the lime-water, until near the bottom of the bottle. Through the other opening thrust a short tube extending only a short distance beneath the stopper. Through the second tube suck the air out of the upper part of the bottle. Ordinary air runs down the first tube and bubbling up through the lime-water gradually produces a

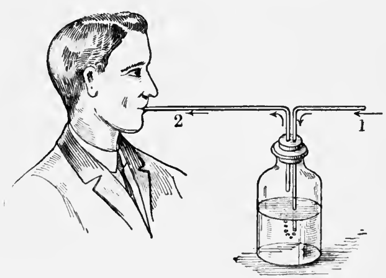


Fig. 78.

milky appearance, thus showing the presence of small quantities of carbon dioxide in ordinary air.

Replace the lime-water with a fresh solution and, reversing the process, blow the breath through the first tube. The milky appearance is produced much more rapidly, thus showing that the lungs give out a greater quantity of carbon dioxide than they take in. In other words, the lungs increase the quantity of carbon dioxide in the air.

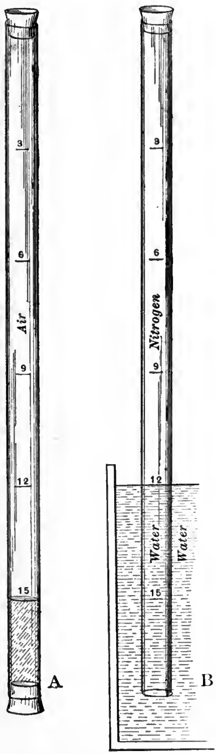


FIG. 79.

142. Method of Securing Nitrogen.— Take a glass tube about 18 inches long, and having an internal diameter of about half an inch. Round the edges at the ends by holding them a short time in the flame of a Bunsen burner and, after cooling, close both ends of the tube by means of rubber stoppers. With a file mark off transverse lines at points 3, 6, 9, 12 and 15 inches from the end of the stopper, closing the upper end of the tube (Fig. 79). This will leave a space of more than 2 inches between the last mark and the stopper at the lower end of the tube. Fill this space with the dark-brown liquid known as potassium pyrogallate and again close the tube. Air now occupies a length of 15 inches (Fig. 79 A). Shake the liquid back and forth in the tube for at least 15 minutes. Then open the lower end of the tube beneath the water surface. Water rushes up into the tube, showing that a

part of the air has been dissolved by the potassium pyrogallate.

In the meantime a large part of the potassium pyrogallate, since it is a heavier liquid than water, escapes into the water beneath. Close the tube and shake it back and forth again. Most of the potassium pyrogallate is now loosened from the walls of the tube and sinks with the water into the lower part of the tube. Open the lower end of the tube again below the water surface, and raise or lower the tube until the water in the tube and in the vessel are at the same level (Fig. 79 B). Then close the tube again. That part of the air which remains in the tube now occupies only $\frac{4}{5}$ as much space as the space originally occupied by the air. It moreover exhibits entirely different properties. It is that part of air known as nitrogen.

143. Presence of Nitrogen in the Air.—Thrust a burning splinter of wood into that part of the air remaining in the tube after the preceding experiment. The flame is extinguished at once. It is evident that the oxygen which was formerly present in the air has been removed by means of the potassium pyrogallate. Moreover the experiment enables us to determine the relative proportion of oxygen in ordinary air. Since $\frac{1}{5}$ of the ordinary air has disappeared at the close of the experiment, this suggests that oxygen forms about $\frac{1}{5}$ of the air. It was seen in a former experiment that the proportion of carbon dioxide in ordinary air is small, in fact, only about $\frac{1}{2500}$ of any volume of ordinary air consists of carbon dioxide. Very small quantities of other gases are also present. Among these argon has recently attracted considerable attention. The gas which remains in the tube in the preceding experiment, however, is nearly all ni-

trogen. Nitrogen, therefore, forms about $\frac{4}{5}$ of ordinary air.

144. Properties of Nitrogen.—Objects placed in nitrogen do not burn. On the contrary, nitrogen extinguishes burning objects. Under ordinary conditions it is impossible to set fire to nitrogen. Mingled with air, it does not explode. Mingled with lime-water, it does not produce a milky appearance. Under ordinary conditions nitrogen is a very inactive or inert gas. It may be distinguished from oxygen, hydrogen, and carbon dioxide by the fact that it does not produce the effects produced by these gases. This inactivity of nitrogen is its most striking characteristic. It weighs slightly less than air.

145. Tests for Oxygen, Hydrogen, Carbon Dioxide, and Nitrogen.—The various properties of the gases so far discussed may be recorded in the form of the following table.

Table indicating the most prominent tests of several colorless gases.	Weight of the gas compared with weight of air.	Causes a glowing splinter of wood to burst into flame.	Enables metals to burn.	Burns when ignited where it comes in contact with air.	Explodes when mixed with air and ignited.	Causes a white precipitate in lime-water.	Extinguishes burning substances.
Oxygen........	$\frac{11}{10}$	+	+				
Hydrogen......	$\frac{1}{14}$	....	......	+	+	......	+
Carbon Dioxide.	$\frac{3}{2}$	....	......	....	....	+	+
Nitrogen.......	$\frac{97}{100}$	....	......	....	....	......	+

From this table it may be seen which tests are most suitable for the rapid identification of any of these gases, provided no other gases are present. If the gas is colorless and odorless, the bursting into flame of the glowing tip of a splinter of wood introduced into the gas indi-

cates the presence of oxygen. The explosion of the gas when it is mingled with air and set on fire suggests hydrogen. The production of a milky appearance, when the gas is passed through lime-water, identifies it as carbon dioxide. The failure of all three of these tests suggests nitrogen.

A much larger number of gases is known to chemists. Sometimes two or three kinds of tests must be used before one of these gases is fully identified.

146. Apparatus used to Determine the Composition of Water.—Cut off the bottom from a large wide-mouthed bottle. If no glass cutter is at hand, this may be accomplished in the following manner. With a new three-cornered file produce a sharp, deep scratch, about half an inch long, near the bottom of the bottle. Heat the end of a poker, or of an iron rod a little thicker than a lead pencil, until it is red hot, then allow it to cool, until the red color has disappeared. Hold the heated end of the poker against one end of the scratch for about four seconds. Reverse the position of the poker and hold it against the other end of the scratch for about eight seconds. Bring it back to its original position and hold it there until the glass cracks. As soon as the glass cracks, draw the poker along the surface of the bottle, keeping it about one-eighth of an inch ahead of the crack. The crack will slowly follow the poker around the bottle. After the bottom of the bottle has been cut off, the sharp edges can be removed with a file.

Secure a cork large enough to close the mouth of the bottle (Fig. 80). Solder two thin strips of platinum $2\frac{1}{2}$ inches long and $\frac{1}{2}$ inch wide, to two strong copper wires. Thrust the wires down through the cork as far as the platinum strips, at such distances apart that it is possible

to slip two test-tubes into the cut end of the bottle and over the platinum strips. Cover the upper side of the cork and the connection between the copper wire and the platinum strips thoroughly with sealing-wax. Insert the cork in the bottle and add sealing-wax around the edge of the cork, so as to form a water-tight vessel, into which the platinum strips project from beneath. If, on trial, the vessel permits a little water to escape, dry thoroughly before adding any more sealing-wax, otherwise the wax will not adhere to the glass.

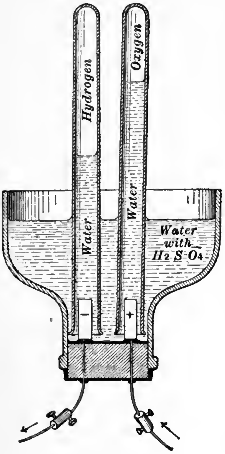


Fig. 80.

Apparatus for use in this experiment, often more complicated, is sold by dealers under the name of Apparatus for the Electrolysis of Water.

147. Composition of Water.—Fasten the bottle on a ring stand and nearly fill it with water. Fill two long test-tubes or combustion-tubes with water. Close the mouth of each test-tube with the thumb or with a rubber stopper, invert the tube, place the end just closed under the surface of the water in the bottle, and then remove the thumb or stopper. The pressure of the air will hold in the water. Slip the mouth of each test-tube over one of the platinum strips (Fig. 80), and fasten the test-tubes in a vertical position so that the tubes cannot move when filled with gas. Remove water from the jar, using a rubber tube as a siphon, until it is certain that if the water in the test-tube were added to the water in the jar there would be no overflow. If the water already contains acid, fill the rubber tube with water; close both

ends with fingers, insert one end in the water in the jar, lower the other end and remove the fingers.

To the copper wires projecting beneath the cork attach the terminal wires coming from an electric battery or dynamo. For the electric battery, six potassium bichromate cells (Fig. 128) will be sufficient. For the student unacquainted with electrical phenomena, it is sufficient to know that the purpose of the battery or dynamo is simply to send a current of electricity through the water.

As soon as the electricity begins to flow, gas bubbles up at the surface of both of the platinum strips and collects at the top of the test-tubes, pushing out the water. The rapidity of the accumulation of gas may be very much increased by mixing sulphuric acid with the water in the proportion of about one to ten. After the flow of electricity has continued for some time, it is seen that the quantity of gas collected in one of the test-tubes is twice as great as that collected in the other.

The gases are colorless and their identity can be established only by experiment. Allow the gases to collect until the tube containing the greater quantity of gas is full. Remove the tube, keeping it in its inverted position, and thrust up into its mouth a burning splinter. The flame of the splinter is extinguished, but the gas burns where it comes in contact with the air. Blow out the flame. Mix the gas with air and bring a lighted match near the mouth of the tube. The mixture explodes. The quantity of gas used is usually too small to break the tube. Hold the tube by means of a handkerchief wrapped around its upper end if you have any reason to expect a stronger explosion. The gas is hydrogen.

By the time the identity of the more rapidly accumu-

lating gas has been determined, the other test-tube will probably be full. Hold the test-tube with the mouth upward and thrust the glowing tip of a splinter of wood down into the gas. The tip bursts into flame. The gas is oxygen.

Only hydrogen is given off in one of the test-tubes, and only oxygen collects in the other. If there were a mixture of these gases in either one of the tubes, there would be an explosion when a burning splinter is thrust in, although the violence of the explosion would depend upon the proportion of each gas in the mixture. No other gas except hydrogen and oxygen can be discovered. At the close of the experiment, nothing is left in the bottle except the sulphuric acid which was added at the beginning of the experiment, and the water which has not yet been separated into hydrogen and oxygen. In other words, the experiment demonstrates that water consists of a combination of hydrogen and oxygen.

Electricity has the power not only of separating water into its component gases, but also of collecting the gases at separate points. The oxygen collects at the platinum strip (+) by means of which the current of electricity enters the water, and the hydrogen collects at the strip (−) by means of which the current of electricity leaves the water.

148. Relative Proportion of Hydrogen and Oxygen in Water.—It is evident that twice as great a volume of hydrogen is produced as of oxygen. If, however, these quantities of gas are weighed (§2) it is found that the one volume of oxygen weighs 8 times as much as the two volumes of hydrogen. Any volume of oxygen, therefore, weighs 16 times as much as an equal volume of hydrogen.

The composition of water may be represented as follows:

$$\underset{(18)}{\text{Water}} = \underset{(2)}{\text{Hydrogen}} + \underset{(16)}{\text{Oxygen.}}$$

The volumetric composition may be suggested in the following manner:

Water = 

(Hydrogen) (Oxygen)

149. Formation of Water from Oxygen and Hydrogen.—If two volumes of hydrogen and one volume of oxygen be placed in a vessel and an electric spark be sent through the mixture, the gases will unite and form water (§ 173).

The production of water from hydrogen and oxygen may, however, be shown in a much more simple form. Attach a platinum tipped nozzle (§ 36) to the end of a delivery tube connected with an apparatus for the securing of hydrogen (§ 137). Collect a test-tube full of hydrogen, and thrust into it a burning splinter. If there is no explosion, there is no admixture of air with the hydrogen coming from the apparatus. Then, and *not till then*, is it safe to light the gas escaping from the platinum nozzle. *A very dangerous and violent explosion may occur if this precaution is not observed.* The danger may be entirely removed by placing the Woulfe bottle in a cage constructed of coarse wire-gauze, permitting only the thistle-tube and the delivery tube to protrude. Any tinner can construct such a cage. In case of explosion the broken glass is then caught by the wire-gauze.

After the hydrogen has been ignited hold the nozzle within the upper part of a cold bell-jar, but not near

enough to crack the jar (Fig. 81). Water collects on the sides of the interior of the jar.

A little thought will show that something unusual has taken place. Heat does not ordinarily cause water to settle on objects. On the contrary, heat is used to drive off water which has settled on any surface, by causing it to evaporate.

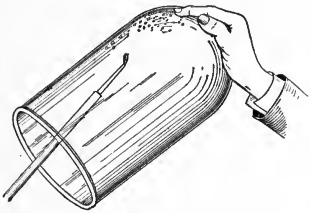


FIG. 81.

But when the hydrogen burns, it unites with the oxygen in the air, and forms water. This water settles on the glass. Directly over the flame the heat usually causes the water to evaporate as rapidly as it settles there, and the upper part of the bell-jar, therefore, usually remains practically dry. On the sides of the bell-jar, however, the water collects more rapidly than it evaporates, and hence the sides of the jar are soon covered with a thin mist, or even with large drops of water.

150. Different Action of Oxygen in Air and Oxygen in Water.—Oxygen in air shows all of the properties of pure oxygen, with only this difference,—its action is relatively weaker. This is due solely to the fact that, in air, the oxygen is diluted with four times its volume of nitrogen, a very inactive gas. (§§ 136, 143.)

Oxygen in water, however, shows entirely different qualities from pure oxygen. Thrust a burning stick into pure oxygen or into air and it continues to burn. Thrust it into water or steam and it is extinguished. Air is the great supporter of combustion. Water is the great enemy of combustion, the most commonly used fire extinguisher.

Moreover, the hydrogen with which oxygen is com-

bined in water, is not an inactive substance like nitrogen. It has already been shown that a mixture of hydrogen and oxygen brought in contact with fire explodes violently, and that hydrogen in contact with air will burn. In fact the heat produced by the union of hydrogen and oxygen is the greatest heat produced outside of the electric furnace. Neither the oxygen nor the hydrogen when combined in the form of water act as these gases usually do either when separate or mixed.

151. Mixtures, Compounds, and Components.—The different action of oxygen in air and in water is explained by the fact that air is merely a *mixture*, and each of the gases in the mixture retains its own characteristic properties. Water, however, is not a mixture of two gases, but a new substance formed from these gases, possessing none of the properties of the gases from which it is formed. A new substance formed by the union of two or more different substances, and having properties dissimilar from those of any of the *components*, is called a *compound*. Hydrogen and oxygen are therefore *components* of the *compound*, water. They are said to be *chemically united*, not mixed, and the force which causes the gases to *unite* is called *chemical affinity*. These expressions are often found convenient. It is well, however, to remember that to have a name for a process is not equivalent to explaining its nature. Although much has been learned about the conditions under which substances unite, and about the proportions in which they combine, practically nothing is known as yet of the real nature of the force called chemical affinity.

152. Analysis and Synthesis.—The composition of a compound substance may be determined either by separating the substance into its components, or by taking the

necessary components and, by a chemical union of these components, producing the compound substance whose composition it is desired to know. The first process is called *Analysis* (loosening the components), the second process is called *Synthesis* (putting together the components).

In the preceding paragraphs the composition of water was determined by both analysis (§ 147) and synthesis (§ 149). There are several methods of analysis. The separation of the components by means of an electric current may be called the *electrolytic* method. The application of a considerable quantity of heat at high temperature is often capable of driving the components of a compound apart. This method of separation may be called the *thermal* method of analysis. The red oxide of mercury may be divided into its components by this method. In order to recognize its components, it is necessary to be able to identify both oxygen and mercury readily.

153. The Properties of Mercury.—When mercury falls upon the floor it usually breaks into countless fragments of all sizes, and each fragment, large or small, assumes the form of a more or less flattened sphere. When mercury is heated gently at the bottom of a test-tube, it evaporates and collects again at the top of the tube, where the glass is still comparatively cold. Often, along the top of the tube, it forms a bright coating, called a *mercury mirror*. A strip of copper wire, dipped into mercury and rubbed, assumes a bright, silvery appearance.

154. The Composition of Red Oxide of Mercury.—Place a small quantity of red oxide of mercury (a powder) in a test-tube. Close the mouth of the tube with a rubber stopper through which passes a glass tube connecting

with the delivery-tube (Fig. 82). Weigh the test-tube with the stopper and powder. Connect the delivery-tube with the test-tube and pneumatic trough, as in the apparatus for the collection of oxygen (§ 134), but, for the sake of economy, use a wide 8-inch test-tube for the collection of any gas that may be given off. Hold the test-tube in a horizontal position, and tap it gently so as to spread out the powder. Heat the powder, being careful to avoid heating intensely any single small spot of the test-tube. Gas begins to escape from the delivery-tube and bubbles

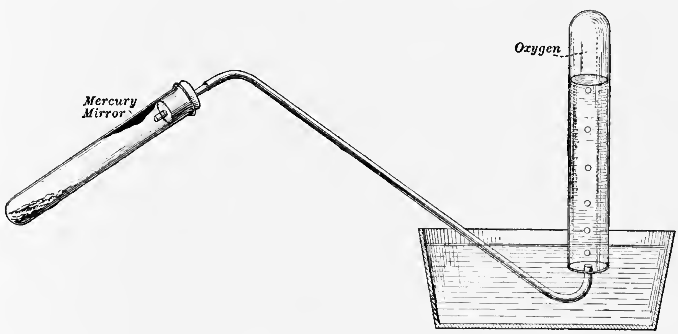


FIG. 82

up through the water. The first portion of the gas is simply the air which filled the tube at the beginning of the experiment and which is expanded by heat. This air should be thrown away. The volume of the gas thrown away should not be much greater than the total volume contained in the delivery-tube and in the test-tube holding the powder. As the test-tube becomes hotter, gas is given off from the oxide of mercury and collects in the 8-inch test-tube. As soon as the disengagement of gas slackens, take the delivery-tube out of the water, taking care that no water remains in the end of the tube. Then,

and *not till then* (§ 134), remove the flame from the test-tube.

Slip a piece of wet filter paper under the mouth of the test-tube containing the gas and turn the test-tube into an upright position. Remove the filter paper and thrust the glowing end of a splinter of wood down into the tube. The glowing tip bursts into flame. This indicates that the gas is oxygen.

Weigh the test-tube containing the powder, together with its contents, and the stopper, as soon as they have cooled to the temperature of the room. There has been a distinct loss in weight. This is due to the loss of the oxygen which was driven off from the powder by the heat.

The material remaining in the test-tube is now not all red oxide of mercury. In the upper part of the tube are found minute globules and also a coating of a bright metallic-looking liquid. In order that this metallic coating may not be driven off by the heat, the upper part of the test-tube must not be heated. Remove the stopper. Invert the test-tube and tap its mouth vigorously on the open palm of the hand. The metallic liquid forms a large drop in the palm of the hand. The drop is probably coated with some of the red oxide of mercury from which the oxygen has not been driven off. This coating can be easily removed with the finger. A piece of clean copper wire, if dipped into the drop and then rubbed, assumes a bright, silvery appearance. If allowed to fall, the drop breaks up into smaller drops of various sizes, and even the smallest drop takes the form of a sphere. The metallic liquid is unquestionably mercury.

If the red oxide of mercury is heated long enough, it completely disappears. Nothing but mercury remains in

the test-tube, and the only substance which has left the test-tube is the oxygen, of which there may be a sufficient quantity to fill a small-sized jar. The red oxide of mercury therefore consists of a combination of oxygen and mercury. This fact was utilized in inventing a name for the substance.

155. The Relative Proportion of Mercury and Oxygen in the Red Oxide of Mercury.—If the weight of the mercury produced from any given quantity of the red oxide of mercury is compared with the weight of the oxygen, it is found that the mercury weighs exactly $12\frac{1}{2}$ times as much as the oxygen.

At ordinary temperatures there is a great difference in the volumes occupied by the mercury and the oxygen obtained from the red oxide of mercury, for, at ordinary temperatures, mercury is in a liquid form, and oxygen is in a gaseous form. The volume of the oxygen, therefore, greatly exceeds that of the mercury, in fact, about 10,104 times at 68° F.

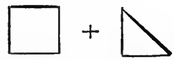
When both are in the gaseous state the difference in volume is much less. If mercury is sufficiently heated it turns into vapor. At high temperatures both mercury and oxygen are in the gaseous condition. If, while both are in the gaseous condition, at the same temperature (for instance 700° F.) and under the same pressure, the mercury and oxygen given off by any quantity of red oxide of mercury be compared, the volume occupied by the mercury will be found to be exactly twice the volume occupied by the oxygen.

This is another illustration of the fact that substances combine in very simple proportions, if the proportions are based upon the volumes of these substances while in a gaseous condition (§ 148).

The composition of the red oxide of mercury may be represented as follows :—

$$\underset{(13.5)}{\text{Red Oxide of Mercury}} = \underset{(12.5)}{\text{Mercury}} + \underset{(1)}{\text{Oxygen}}.$$

The volumetric composition may be indicated in the following manner :

Red Oxide of Mercury = 

(Mercury) (Oxygen)

156. All Components of a Compound not Always Readily Detected.—In the preceding experiments, illustrating the electrolytic and thermal methods of analysis, it was possible to recognize readily both components of the compounds examined. In many compounds it is possible to identify only one component with ease.

If, for instance, a solution of copper sulphate is poured into the bottle prepared for the electrolysis of water (§ 146), and a current of electricity is sent through the solution, copper is deposited on one of the platinum strips. The only source from which the copper could have come is the copper sulphate, since the tops of the copper wire holding the platinum strips are buried beneath the sealing wax. Copper is, therefore, one of the components of copper sulphate. The other components undergo chemical changes not here explained. They remain dissolved in the water, and since they possess no distinctive color they cannot be seen.

Instead of using the electrolysis apparatus, wires from the battery or dynamo may be connected to two electric-light carbons, and the ends of these carbons may be dipped into the copper sulphate. When a current is sent through the solution, the copper is deposited on one of

the carbons. The copper adheres better to the platinum or carbon, if it is deposited slowly by a weak current of electricity.

If the current of electricity is allowed to flow until all the copper in the copper sulphate solution has settled upon one of the platinum strips or electric-light carbons, the weight of the copper is found to be exactly $\frac{63}{249}$ or $\frac{21}{83}$ of the entire weight of the copper sulphate crystals originally placed in the water.

Copper Sulphate	=	Copper	+	Other Components
(249)		(63)		(186)

157. Substitution, or the Replacement of one Component of a Compound by another Substance.—The presence of copper in copper sulphate may be demonstrated by a method which does not require the application of either electricity or heat.

Pour a small quantity of a solution of copper sulphate into a test-tube. Place a large bright wire nail in the tube. Close the tube with the thumb and repeatedly tip it, so that the solution covers the nail and recedes again. Copper settles on the iron.

If the nail is taken out of the test-tube as soon as the copper covering is distinctly seen (a few seconds are usually enough) and if the coating is first allowed to dry and is then vigorously rubbed with cloth, the characteristic color of smooth copper may be recognized. The other components of copper sulphate, however, remain in the solution, as in the case of the preceding experiment, and, since they exhibit no distinctive coloring, their presence again escapes detection.

If the nail is allowed to remain in the copper sulphate for a long time, the copper coating increases in thickness,

but it no longer adheres well to the nail and may easily be rubbed off. If now the nail is closely examined, it is discovered that the surface is distinctly roughened, owing to the disappearance of that part of the iron which once formed the smooth surface of the nail. The pitted character of the surface may be distinctly recognized under a lens, and a comparison with another nail of the same kind shows that its diameter has been perceptibly diminished. The iron disappears while the quantity of copper which settles on the nail increases. The iron takes the place of the copper in the copper sulphate solution.

Copper has an attraction for the other components of copper sulphate. From the experiment it appears that iron also has an attraction for these components. In fact, it seems to have a stronger attraction for them than does copper. The iron therefore pushes the copper away from the other components of copper sulphate and takes its place. In other words, iron is *substituted* for copper in copper sulphate and it forms a new substance, called iron sulphate. The copper which is pushed aside settles upon the iron nail.

If enough iron is placed in the copper sulphate solution to replace all of the copper, the color of the solution gradually changes from the blue of copper sulphate to the green of iron sulphate. If the excess of iron with its copper coating is taken out and the water is removed by heating the solution in an evaporating dish, the iron sulphate is left behind and may easily be recognized as something quite distinct from copper sulphate. The chemical change may be expressed as follows:

$$\underset{(63)}{[\text{Copper}} + \underset{(186)}{\text{Other components}]} + \underset{(55.6)}{\text{Iron}} = \underset{(55.6)}{[\text{Iron}} + \underset{(186)}{\text{Other components}]} + \underset{(63)}{\text{Copper}}$$

$$(\text{Copper sulphate}) + \text{Iron} = (\text{Iron sulphate}) + \text{Copper}$$

This is one of the simplest illustrations of the identification of one component of a compound by *chemical substitution.*

158. Identification of Components of Compounds by Color of Precipitates.—In the cases of analysis of compounds so far discussed, the components which were *identified* were secured *free* from union with any other substance. It is often possible to recognize the presence of one or more of the components of a compound without securing them in the free state, in other words—without obtaining them uncombined with any other substance.

Dissolve about 1.7 of an ounce of potassium bichromate in one pound of water. Mingle a small quantity of nitric acid with 4 times its volume of water. Pour a small part of the nitric acid solution into a test-tube and add a little of the potassium bichromate solution. Nothing is noticed beyond the mingling of the two liquids.

In another test-tube place a small piece of silver (coin), add dilute nitric acid and heat for a short time in the flame of a Bunsen burner. A part of the silver disappears in the acid solution. Pour a little of the acid solution into a third test-tube, dilute it still farther with water (pure distilled water), and again add a little of the potassium bichromate solution. The mixture becomes clouded with a dark red substance, which evidently can be due only to the presence of silver in some form in the acid solution. Most of this dark red substance promptly settles to the bottom of the test-tube. This portion consists of the heavier particles. The lighter particles remain suspended for a long time in the liquid, but finally these also are found at the bottom of the tube. Hence the dark red substance is called a *precipitate.*

Now, chemists have tested the effect of pouring potas-

sium bichromate into the solutions of all sorts of substances whose compositions are known, and, while they have succeeded in getting precipitates in some of these cases, the color of none of these precipitates was dark red, excepting in those cases where silver was present in some form or other in the solution. Having once established this fact, the presence of a dark red precipitate on the addition of potassium bichromate to the solution of any unknown substance is at once an evidence of the presence of silver in this substance.

Chemicals which are used for the purpose of ascertaining the presence of various substances in compounds are often spoken of as *reagents*. Potassium bichromate is only one of a great many reagents used to produce precipitates.

159. Several Tests Often Necessary to Determine Definitely the Presence of a Substance in a Compound.— Potassium bichromate produces precipitates only when one of the following substances is present in the unknown compound which is in solution: lead, silver, mercury, bismuth, and barium. The presence of any precipitate on the addition of potassium bichromate to the solution of an unknown compound, therefore, is at once an evidence of the presence of one or more of these five substances in the compound. However, since many of these precipitates are yellow, the formation of a precipitate on the addition of potassium bichromate is not sufficient to determine which metal is present in the compound.

But other reagents also form precipitates and the color of these precipitates varies so much, that it is often possible, if several reagents are used in succession, to determine with confidence the presence of a substance in an unknown compound even in cases when the use of a single reagent leads to no definite result.

This fact is shown by the following table. In the first column are placed the names of the different substances which give rise to precipitates when the compounds containing them are dissolved in water, and when some one of the three reagents named at the head of the following columns is added. Opposite the names in the first column are indicated the colors of the precipitates formed on the addition of these reagents. When no precipitates are formed, the space is left blank.

COMPOUNDS CONTAINING THESE METALS TO BE TESTED.	REAGENTS.		
	Potassium Bichromate.	Potassium Iodide.	Hydrochloric Acid.
Lead	Yellow.	Bright yellow.	White.
Silver	Dark red.	Yellow-white, darkening on exposure.	White, blackening on exposure.
Mercury.........	Yellowish green to red.	Greenish yellow to red.	White.
Bismuth.........	Orange yellow.	Dark brown.	
Copper..........	....	White to yellow to brownish yellow.	
Antimony........	....	Yellow.	
Barium..........	Light yellow.		
Palladium........	....	Black.	

Suppose potassium bichromate is added to the solution of some unknown compound and a yellowish precipitate is formed. If neither potassium iodide nor hydrochloric acid form a precipitate when added to a fresh quantity of the same unknown solution, barium is probably present in the compound. If potassium iodide gives a dark brown precipitate, bismuth is one of the components. In this case, hydrochloric acid should produce no precipitate. If potassium iodide produces a yellow precipitate, the unknown compound contains lead. In this case hy-

drochloric acid produces a white precipitate. If a small quantity of potassium bichromate produces a yellowish green precipitate, and if a greater quantity of the reagent produces a distinctly greenish or reddish precipitate, mercury is present. Suppose the addition of potassium bichromate produces a reddish precipitate of such a tint that it is impossible to determine whether silver or mercury is present. The addition of potassium iodide should at once decide this matter.

160. Method of Separation of Different Precipitates Formed by the Same Reagent.—When a compound or a mixture of compounds contains several substances which will give precipitates with the same reagent, it is necessary to separate these substances before their identity can be fully established. This is especially true when the different precipitates have about the same color. This separation may often be easily accomplished if the different precipitates vary considerably as to their solubility in the different reagents. This may be illustrated by the following example.

When dilute hydrochloric acid is added to all known solutions of compounds, precipitates are formed only when lead, silver, and mercury are present. Hence the formation of a precipitate on the addition of hydrochloric acid is at once an evidence of the presence of either lead, silver, or mercury, or of any two of these substances, or of all three of them. Since all of these precipitates are white, it is impossible to determine from the color alone which substance or substances are present.

The precipitates differ, however, considerably in the readiness with which they dissolve in various substances, and this fact may be utilized in the identification of the metal present in the unknown compound. For instance,

the precipitate due to the presence of lead dissolves readily in hot water, but those due to the presence of silver and mercury do not dissolve in hot water. The precipitate due to the presence of silver dissolves in warm dilute ammonia water, while the precipitate due to the presence of mercury turns black and does not dissolve. The following method of procedure will make it possible to determine which substances caused the precipitates due to the addition of hydrochloric acid.

Place a filter paper in a funnel supported on a ring stand. Put a beaker directly beneath, and pour the precipitates with the liquid in which they were formed into the funnel. The precipitates remain on the filter paper; the liquids (filtrates) pass through and escape at the bottom. Pour water gently over the precipitates until they are thoroughly clean. Then punch a hole through the bottom of the filter paper, and, with a little water, wash the precipitates into a second small glass beaker. Add water to the precipitates, place the beaker on a wire gauze on a ring stand (Fig. 83) and boil for a short time. If all of the precipitate disappears, only lead is present.

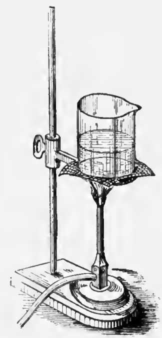


FIG. 83.

If all of the precipitate does not disappear after boiling in plenty of water, filter mixture while hot. If any lead is present, white needle-shaped crystals will appear in the filtrate on cooling. The precipitate remaining on the filter paper contains either silver or mercury, or both.

Wash the precipitate left on the second filter paper into another beaker, add ammonia water, and warm the mixture. If only silver is present, all of the precipitate

disappears. If the precipitate turns black, mercury is present. In order to determine whether silver is present in addition to the mercury, filter the black mixture and add dilute nitric acid to the filtrate, until the filtrate changes the color of litmus paper from blue to red. If a white precipitate appears, silver is present.

Lead is first separated from silver and mercury, and then silver is separated from mercury. After the separation, the other tests with potassium bichromate and potassium iodide may be applied.

161. Elements.—The preceding paragraphs by no means describe all of the methods employed by chemists to determine the components of a compound, but they at least make evident that there are methods for attacking such problems.

Chemists have been at work for many years in determining the components of all kinds of compounds, and, wherever possible, in determining even the components of these components. Whenever none of the methods at the command of a chemist enable him to subdivide any component into two or more other components, the last component obtained is called an *element*. It is impossible, of course, to determine definitely what substances are elements, since new methods of analysis may in the future enable the chemist to subdivide those which are now universally considered as elements. But it is easily possible to determine what substances have not yet been subdivided and must therefore be considered elements for the present.

An element is a substance which cannot, by any method at present known to chemists, be divided into two or more dissimilar substances.

Nearly 80 substances are at present considered as ele-

ments (§ 181). Most of these are known only to the chemist, since they rarely exist uncombined in nature. Among the most commonly known elements are the metals: aluminum, copper, gold, iron, lead, mercury, nickel, platinum, silver, tin and zinc. Brass is not an element but a mixture chiefly of copper and zinc. Bronze is a mixture of copper, tin and zinc. Arsenic, carbon, phosphorus and sulphur are elements. The gases, hydrogen, nitrogen, and oxygen are elements. Some elements are exceedingly common in nature, but are seen uncombined with other elements in chemical laboratories only. Among these are silicon and calcium. Aluminum has only recently become one of those metals commonly seen outside of the chemical laboratory. In fact, until recently it was a very expensive metal, and difficult to obtain.

162. Chief Elements Present in the Earth.—Nearly 50 per cent. of the solid crust of the earth consists of oxygen, and a little more than 25 per cent. consists of silicon, so that the non-metallic elements, oxygen and silicon, form nearly 75 per cent. of the crust of the earth; while almost all of the remainder is formed by the metals: aluminum, 8 per cent.; iron, 5 per cent.; calcium, 4 per cent.; magnesium, 2.5 per cent.; sodium, 2.5 per cent., and potassium, 2.5 per cent. The other rock-forming elements—titanium, carbon, hydrogen, phosphorus, manganese, sulphur, and chlorine—form scarcely 1 per cent. of the crust.

The rock-forming compounds are usually known as *minerals*. Compounds or mixtures of compounds which are commercially valuable as sources of metals are usually called *ores*.

163. Chief Elements Found in Plants.—Water forms by far the largest part of most plants. While green they

contain from 75 to 91 per cent. of water. Even so-called dry wood contains usually 15 per cent. of water.

After the water present in plants has been completely evaporated, there remain, in a dried condition, those compounds which once formed the more solid parts of the roots, stems, leaves, flowers, and fruits. These organic compounds consist chiefly of carbon, oxygen, hydrogen, and nitrogen. If these compounds are burned, the gaseous substances due to combustion escape, and only the mineral constituents remain. The mineral constituents, called *ash* when left as the result of burning, form by far the smallest part of plants. Usually less than 3 per cent. of a plant remains in the form of ash, and many juicy plants contain less than 1 per cent. of mineral material. In the ash, potassium, calcium, magnesium, and phosphorus are always present in an appreciable amount. Iron, chlorine, sulphur, and sodium are also present, but usually in very small quantities. Silicon occurs in various grasses, sedges, rushes, and other plants. Iodine is found in some sea plants.

164. The Chief Elements Present in the Animal Body.— It has been calculated that in an average man weighing 154 pounds, 116 pounds consist of water which may be driven off as moisture, and 29 pounds consist of the flesh, skin, blood, fat, and gelatine after all the water has been driven off. If the body were burned, the water and the organic compounds would disappear and only the mineral matter would be left behind. This would consist chiefly of what was left of the bones, a total of only about 10 pounds.

Oxygen forms about 72 per cent. of the human body; carbon, 13.5; hydrogen, 9.1; nitrogen, 2.5; calcium, 1.3; phosphorus, 1.15; sulphur, 1.47; sodium, .1; chlorine,

.085; fluorine, .08; potassium, .026; iron, .01; magnesium, .0012; and silicon, .0002. The great quantity of oxygen and hydrogen is largely due to the abundance of water in all the tissues. Many organic compounds in the body contain sulphur. Calcium and phosphorus are among the most important constituents of bones. Sodium and chlorine are present in the form of salt dissolved in the various liquids of the body.

165. Organic Compounds.—Plants and animals are able to produce many compounds not otherwise found in nature. Among these may be mentioned, sugar starch, oil, wood, fat, muscle, and bone. About 75 years ago it was believed that chemists never would be able to duplicate any of these compounds, and hence a very careful distinction was made between the compounds not produced by living organisms, and those which could be produced only by plants and animals. The first were called *inorganic* compounds, and the second, *organic* compounds. At present, however, many of the so-called organic compounds, such as sugar and starch, can be produced in the laboratory.

166. The Chief Difference between Animals and Plants.—If the student is acquainted with only the larger animals and plants, he will not find it difficult to find many distinctions between these two divisions of the living world. If he knows also the microscopic animals and plants, he will find that many distinctions which can readily be made between the larger forms cannot be retained as a means of separation between all of the smaller animals and plants. For instance, it was once supposed that animals are capable of motion and plants are not. But now it is known that various parts of plants are in continual, although very slow, motion; some sensitive plants close

their leaves as soon as touched; some insect-catching plants close their leaves too rapidly for the insects to escape; and some microscopic plants in some stages of their existence can swim around freely in the water even in a direction opposite to that of the current.

There is, however, one difference which will serve better as a distinction between animals and plants than any of the rest. Animals can not manufacture organic compounds from inorganic substances. They must obtain substances which are already organic compounds, and they use these to manufacture from them new organic compounds. Plants, however, can manufacture organic compounds from inorganic materials. Plants, therefore, can live on the inorganic materials they secure from the earth, the water, and the air; but animals must live on plants, or on animals which have eaten plants.

167. Water and Air are the Sources of the Chief Constituents of Plants and Animals.—The chief constituents of animal and vegetable bodies, aside from water, are the carbon compounds. In addition to carbon, most of these compounds contain hydrogen and oxygen, and often also nitrogen, all of which are non-metallic elements. In marked contrast with the comparatively *small* importance of carbon, hydrogen, and nitrogen in *rock-forming minerals*, is their *great* importance in *animal and vegetable compounds*.

A large part of the hydrogen and oxygen used by plants is secured from the water which is present in the soil. Both animals and plants secure oxygen also from the air, the process being called breathing. Nitrogen forms four-fifths of the air, but plants take in nitrogen by way of the roots. Carbon united with oxygen, in the form of carbon dioxide (§ 141), is present as a very

minor constituent of the air, but this small quantity is of the greatest importance, since it provides most of the carbon used by plants. The supply of carbon dioxide in the air is continually replaced by the decay of animal and vegetable bodies.

Animals secure carbon and nitrogen by eating plants or animals that have eaten plants.

168. Elements are Usually Found Combined in Nature.— Most elements unite so readily with other elements that their natural condition may be said to be a state of combination. Even some of those elements which are found free in nature occur more frequently combined than uncombined. This is true, for instance, of oxygen, carbon, and sulphur. Nitrogen is also frequently found in combination in the organic compounds present in animal and vegetable bodies.

Some elements can unite with nearly all of the other elements. This is true to a remarkable degree of oxygen, chlorine, and sulphur. Other elements, like gold, appear to unite with but few other substances. For this reason, gold is often found as a pure metal in the form of nuggets. Elements which combine with difficulty with other elements are said to be *inert.* Very few elements are inert. If an element is desired in the free uncombined state, it is usually necessary to secure some compound in which the element is present, and then by some means separate the element from the rest of the compound, in such a manner that the element will remain separated from all other substances. Some elements are so active that special precautions must be used in order to retain them in the free state. Phosphorus must be kept under water. Potassium and sodium must be kept under naphtha or benzene.

169. The Formation of Compounds by Direct Combination.—Since a state of combination is the natural condition for most elements, it is a comparatively easy matter to illustrate the various methods of combination.

The *direct* combination of two elements is shown when hydrogen is burnt in air. It unites with oxygen and forms water (§ 149). Chlorine is a poisonous gas, not suitable for experiment in an ordinary classroom not provided with special apparatus for carrying off obnoxious gases. However, it may be interesting to know that if

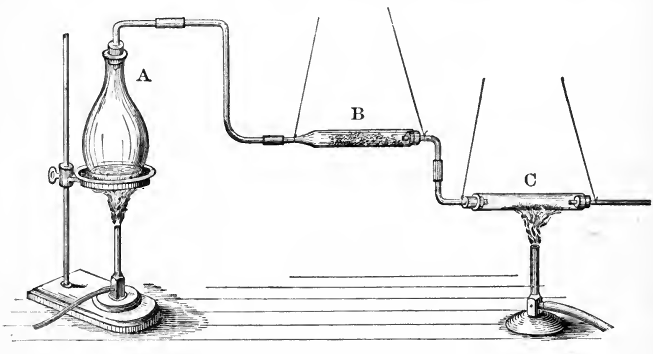


FIG. 84.

equal volumes of chlorine and hydrogen are placed in direct sunlight, they unite so rapidly as to cause a violent explosion. The compound formed is hydrochloric acid.

When iron is burnt in oxygen (§ 135), a black compound, black iron oxide, is produced. Red hot carbon (charcoal) placed in oxygen will burn and produce carbon dioxide.

If a current of chlorine is passed over iron filings heated in a hard glass tube (Fig. 84 C), the chlorine and iron unite with such rapidity that the iron becomes white hot.

Iron chloride is the result. To secure the chlorine, place in a flask, A, a third of an ounce of manganese dioxide, and an ounce of common hydrochloric acid, and *gently heat* the mixture. To dry the gas, pass it through a tube filled with lumps of calcium chloride, B.

Mix thoroughly $\frac{5}{10}$ of an ounce of fine iron filings with $\frac{3}{10}$ of an ounce of sulphur. Place about one-fourth of the mixture in a test-tube, and heat until the mixture glows. The sulphur unites with the iron, producing a bright light and forming iron sulphide.

Mix thoroughly $\frac{1}{10}$ of an ounce of coarsely powdered sulphur with $\frac{3}{10}$ of an ounce of copper filings. The mixture presents neither the lemon-yellow color of sulphur nor the well-known color of copper. The sulphur and copper, however, have not united. If the mixture be examined under the microscope, the particles of sulphur may still be recognized among the particles of copper. With the exercise of sufficient care and diligence, the particles of sulphur may be picked out from the mixture, and thus may be separated from the copper. If the mixture be thrown into water, the copper will sink to the bottom at once, while the sulphur, which weighs less than one-fourth as much, will sink more slowly through the liquid. This method may also be used for the separation of the sulphur from the copper

Put the mixture into a tube of hard glass (test-tube or ignition-tube), and heat it with a Bunsen burner. The sulphur melts, catches fire, and unites with the copper, producing a brilliant light. When no further change takes place, allow the tube to cool, break it, and examine the contents. Sulphur and copper have disappeared as such. A new substance has appeared, which, though containing both the sulphur and the copper, has no external

resemblance to either, and possesses new properties. It is the chemical compound, copper sulphide.

170. Formation of New Compounds by Substitution.—Many compounds are formed, not by direct union of the elements, but by substituting some other element for one of the elements of a compound, thus forming a new compound. Hydrochloric acid consists of hydrogen and chlorine (§ 169). When zinc is placed in hydrochloric acid it takes the place of the hydrogen, and forms zinc chloride. The hydrogen which is no longer combined escapes (§ 137). When iron replaces copper in copper sulphate, a new compound is formed, iron sulphate (§ 157).

$$\text{Zinc} + \underset{\text{(Hydrochloric acid)}}{\left\{\begin{matrix}\text{Hydrogen}\\ \text{Chlorine}\end{matrix}\right.} = \underset{\text{(Zinc chloride)}}{\left\{\begin{matrix}\text{Zinc}\\ \text{Chlorine}\end{matrix}\right.} + \text{Hydrogen}$$

$$\text{Iron} + \underset{\text{(Copper sulphate)}}{\left\{\begin{matrix}\text{Copper}\\ \text{Sulphur}\\ \text{Oxygen}\end{matrix}\right.} = \underset{\text{(Iron sulphate)}}{\left\{\begin{matrix}\text{Iron}\\ \text{Sulphur}\\ \text{Oxygen}\end{matrix}\right.} + \text{Copper}$$

171. The Formation of New Compounds by Double Substitution, or Double Decomposition.—In order to illustrate the formation of compounds by direct combination and by substitution, simple cases have been selected. Usually the processes are more complicated but the principles remain the same. One of the most interesting and most common of these complicated cases is seen when two compounds are brought into contact, and by a partial or complete interchange of elements produce new compounds.

When two compounds are brought in contact with each other, one of the elements in one compound may be substituted for one of the elements in the second compound,

and the element displaced from the second compound may take the place left vacant in the first compound. This evidently results in an interchange of elements between the compounds. The process may be called *double substitution*, or, if emphasis be laid on the breaking up of the molecules of the original substance preparatory to the formation of new molecules, it may also be called *double decomposition.*

Potassium iodide consists of potassium and iodine. If solutions of lead nitrate and potassium iodide are brought together, the lead and potassium exchange places, and the new compounds, lead iodide and potassium nitrate, result. The lead iodide is seen as a bright yellow precipitate (§ 159). The potassium nitrate remains in solution, but if the water is filtered and then boiled the potassium nitrate remains as a colorless or white substance resembling salt in appearance.

$$\begin{array}{ccccccc} \left\{\begin{array}{l}\text{Lead}\\ \text{Nitrogen}\\ \text{Oxygen}\end{array}\right. & + & \left\{\begin{array}{l}\text{Potassium}\\ \text{Iodine}\end{array}\right. & = & \left\{\begin{array}{l}\text{Lead}\\ \text{Iodine}\end{array}\right. & + & \left\{\begin{array}{l}\text{Potassium}\\ \text{Nitrogen}\\ \text{Oxygen}\end{array}\right. \\ \text{(Lead nitrate)} & & \text{(Potassium iodide)} & & \text{(Lead iodide)} & & \text{(Potassium nitrate)} \end{array}$$

One of the most interesting cases of double decomposition is the formation of common table salt and water from two poisons, sodium hydrate or caustic soda, and hydrochloric acid. Dissolve caustic soda in water (6 parts, by weight, of caustic soda to 50 parts of water). Pour half a test-tubeful of this solution into a porcelain evaporating dish, and add, drop by drop, diluted hydrochloric acid (4 parts of water to 1 part of the commercial acid). Stir the mixture after the addition of each drop and test with litmus paper (§ 67), until the mixture no longer turns litmus paper from red to blue. By this time the solution is likely to have dissolved considerable

litmus from the litmus paper. If the number of drops of acid used has been counted, the experiment can be brought up quickly to about the same stage by taking another half test-tubeful of the caustic soda solution, adding at once the number of drops of acid used before, and then testing once more by dipping as little of the litmus paper in the solution as possible. If too much acid has been used, a drop or more of caustic soda solution must be added. When red litmus paper is no longer changed to blue, and blue litmus paper is no longer changed to red, both hydrochloric acid and the alkali, sodium hydrate, are gone.

Pour a few drops of the hydrochloric acid solution into a test-tube, one-eighth full of water. Taste one drop of the mixture on a glass stirring rod. Taste a similarly diluted solution of the caustic soda. Taste a drop of the mixture just formed in the evaporating dish, without diluting the mixture. The tastes of the three are different: sour, alkaline, salty.

Sodium has taken the place of hydrogen in hydrochloric acid, and has formed common table salt. At the same time the hydrogen which was displaced has taken the place vacated by the sodium, and has united with the oxygen and hydrogen, and formed water. The solution left in the evaporation dish is simply a solution of salt in water. If the water is evaporated, the salt is left behind. If the solution has not dissolved too much litmus, the salt left in the evaporating dish is pure and white.

$$\begin{array}{ccccccc} \left\{\begin{array}{l}\text{Sodium}\\ \text{Oxygen}\\ \text{Hydrogen}\end{array}\right. & + & \left\{\begin{array}{l}\text{Hydrogen}\\ \text{Chlorine}\end{array}\right. & = & \left\{\begin{array}{l}\text{Sodium}\\ \text{Chlorine}\end{array}\right. & + & \left\{\begin{array}{l}\text{Hydrogen}\\ \text{Oxygen}\end{array}\right. \\ \begin{array}{c}\text{(Sodium}\\ \text{hydrate)}\end{array} & & \begin{array}{c}\text{(Hydrochloric}\\ \text{acid)}\end{array} & & \text{(Salt)} & & \text{(Water)} \end{array}$$

172. The Law of Conservation of Mass.—If any of the preceding chemical experiments be performed in a vessel closed in such a manner that it is impossible for any material to enter it or to escape from it, it will be found that the total weight of the vessel and of its contents is the same both before and after the chemical change takes place. In other words, there is neither gain nor loss of material during any chemical change. The change consists merely in a different arrangement of the elements. A compound may be separated into its components or elements. Elements may unite to form a compound. Or, the components of different compounds may first separate and may then unite in such a manner as to form compounds different from the original substances. In each case the same fact is observed.

The total weight of all the products of a chemical change is exactly equal to the sum of all the weights of all the substances affected by the change.

173. Law of Definite Proportions by Weight.—It has been shown that the red oxide of mercury consists of mercury and oxygen. It is possible to separate these elements in such a manner that the weight of each can be determined accurately. The weight of mercury and oxygen present in red oxide of mercury depends, of course, upon the quantity of the compound taken for analysis. If, however, a number of analyses are made and the weights of the component elements are determined, the interesting fact is discovered that in all cases the quantities of mercury and oxygen are present in the same relative proportion. If, for instance, 28.35, 49.95, 189, and 245.83 ounces of the red oxide of mercury were analyzed, the following weights of mercury and oxygen would be obtained :

Oxide of Mercury.		Mercury.		Oxygen.	Proportion of Mercury to Oxygen.
28.35 oz.	=	26.25	+	2.10	12.5 : 1
49.95	=	46.25	+	3.70	12.5 : 1
189.00	=	175.00	+	14.00	12.5 : 1
245.83	=	227.62	+	18.21	12.5 : 1

If, in a similar manner different quantities of water are analyzed, the relative proportion of oxygen and hydrogen present is found to be always the same: the weight of the oxygen is in each case 8 times the weight of the hydrogen.

The constancy of the relative proportion of the elements in different quantities of the same compound may also be shown by carefully determining the weights of the different elements which enter into combination during the formation of some compound.

If 8 times as great a weight of oxygen as of hydrogen is imprisoned in any long test-tube inverted in water, and if a spark of electricity is sent through the mixture (§ 149), all of the mixture enters into combination, and forms water. Since the water formed from the gas occupies much less volume than the gas, this results in a temporary vacuum and the water in which the test-tube is inverted rushes up, so that the water formed from the mixture of oxygen and hydrogen and the water rushing up into the test-tube from the outside completely fill the tube.

If, however, other proportions are taken, all of the gaseous mixture does not enter into combination. If 1.72 ounces of hydrogen and 15.41 ounces of oxygen are placed in a vessel and united by sending a spark of electricity through the mixture (Fig. 85 A), and if the water is allowed to enter the vessel so as to fill the partial vacuum, it is found that the water resulting from combination, and

the water rushing in from the outside are prevented from filling all the space in the vessel by the presence of some gas, evidently a part of the original mixture. If the gas left uncombined is examined it is found that the gas is pure oxygen and that its weight is 1.65 ounces (Fig. 85 B). Therefore all the hydrogen entered into combination, but only 13.76 ounces of oxygen united with the hydrogen. But 13.76 ounces are exactly 8 times 1.72 ounces. Therefore exactly 8 times as much oxygen as hydrogen enters into combination, even if an excess of oxygen exists in the mixture. If an excess of hydrogen had been used, only $\frac{1}{8}$ as much hydrogen, by weight, as oxygen would have entered into combination. The remainder of the hydrogen would have remained uncombined.

In actual experiments the weights of the materials used are much smaller than those indicated by the figures here given, but the principle remains the same.

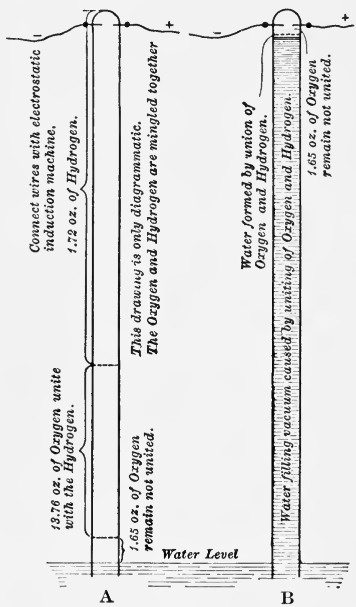


FIG. 85.

The same principle may be readily shown, provided a delicate balance is at hand. Place different weights of magnesium (in the form of ribbon) in porcelain crucibles, and heat the crucibles until the magnesium unites with the oxygen in the air, and produces a white compound,

magnesium oxide, easily reduced to powder by a mere touch. The quantity of oxygen entering into combination, as shown by the increased weight of the material in the crucible, varies in each case, but the proportion of oxygen as compared with that of the magnesium is always the same: in each case the weight of the oxygen entering into combination is $\frac{2}{3}$ of that of the magnesium. Of all the oxygen in the air only that quantity enters into combination which is necessary to preserve this proportion. If not enough oxygen were at hand, a part of the magnesium ribbon would remain uncombined.

From these and similar facts, the following law, known as the *Law of Definite Proportions*, has been derived:

The same chemical compound always contains the same elements in the same proportion by weight.

The proportion of the weight of any element, forming part of a compound, to the total weight of the compound is always the same.

174. The Law of Multiple Proportions by Weight.—Whenever hydrogen and oxygen unite directly, they unite in one proportion only and always form water. However, by a process of double substitution it is possible to secure another compound in which these elements are united in a different proportion. When, for instance, small quantities of barium dioxide are introduced in succession into cold, dilute hydrochloric acid, the barium and hydrogen exchange places, and two new compounds are formed, barium chloride and hydrogen dioxide.

$$\left\{\begin{array}{l}\text{Barium}\\\text{Oxygen}\end{array}\right. + \left\{\begin{array}{l}\text{Hydrogen}\\\text{Chlorine}\end{array}\right. = \left\{\begin{array}{l}\text{Barium}\\\text{Chlorine}\end{array}\right. + \left\{\begin{array}{l}\text{Hydrogen}\\\text{Oxygen}\end{array}\right.$$

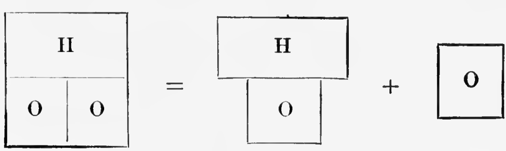
Now when the hydrogen dioxide is analyzed it is discovered that the proportion of oxygen is much greater

than in water; in fact, there is 16 times as much oxygen, by weight, as hydrogen, while in water the proportion of oxygen is only 8 times that of hydrogen. This shows that two elements can unite in more than one proportion, in order to form compounds.

The hydrogen dioxide has very different properties from water. It is a syrupy liquid, and weighs 1.45 times as much as water. It corrodes the skin, destroys the coloring matter in plants, and is used in surgical operations to kill any germs which may come in contact with the wound. It readily loses half of its oxygen when heated to 200° F., and the remainder becomes ordinary water. Owing to the fact that hydrogen dioxide contains exactly twice as much oxygen as water, the relation between hydrogen dioxide and water may be expressed in the following manner (§ 147):

$$\left\{\begin{array}{l}\text{Hydrogen}\\ \text{Oxygen}\\ \text{Oxygen}\end{array}\right. \quad + \quad \left\{\begin{array}{l}\text{Hydrogen}\\ \text{Oxygen}\end{array}\right. \quad = \quad \text{Oxygen}$$

$$\text{(Hydrogen dioxide)} \quad = \quad \text{(Water)} \quad + \quad \text{(Oxygen)}$$



(Hydrogen dioxide) (Water) (Oxygen)

Hydrogen dioxide, usually more or less diluted with water, may be purchased under the name hydrogen peroxide.

Cases in which elements unite in more than one proportion are rather common, but different conditions must be utilized to induce the elements to unite in these differ-

ent proportions, and each proportion produces a different compound with different properties.

Nitrogen and oxygen unite in 5 different proportions. When these elements unite in such proportions that the weight of the oxygen is exactly .57 as great as that of the nitrogen, *nitrogen monoxide* is produced. It is a colorless and odorless gas, but possesses a sweetish taste. It is used by dentists to deaden pain, and is often called laughing gas.

When nitrogen and oxygen unite in such proportion by weight, that the oxygen weighs exactly 1.14 times as much as the nitrogen, the compound *nitrogen dioxide* is produced. It is a colorless gas, and is chiefly characterized by the fact that as soon as it is exposed to the air it takes up more oxygen, and forms red vapors, *nitrogen tetroxide.*

When the proportion by weight in which the elements unite is 1.71 times as much oxygen as nitrogen, the compound *nitrogen trioxide* is produced. It is a blue liquid.

When 2.28 times as much oxygen as nitrogen unite, the compound *nitrogen tetroxide* is produced. It is an orange-brown liquid. Its vapor, however, is red, and is very corrosive and dangerous to inhale.

When 2.85 times as much oxygen as nitrogen unite, *nitrogen pentoxide* is produced. It is a white solid substance and is liable to explode.

An examination of the last four compounds shows that the proportion of oxygen as compared with the nitrogen is 2, 3, 4, and 5 times the proportion of oxygen present in the first compound, nitrogen monoxide.

The chemical composition of these compounds may be expressed in the following manner :—

Nitrogen	Nitrogen	Nitrogen	Nitrogen	Nitrogen
Oxygen	Oxygen	Oxygen	Oxygen	Oxygen
	Oxygen	Oxygen	Oxygen	Oxygen
		Oxygen	Oxygen	Oxygen
			Oxygen	Oxygen
				Oxygen
(Nitrogen monoxide)	(Nitrogen dioxide)	(Nitrogen trioxide)	(Nitrogen tetroxide)	(Nitrogen pentoxide)

In many cases the series are not so complete. For instance, iron and phosphorus unite in the following proportions with chlorine:

Iron	Iron	Phosphorus	Phosphorus
Chlorine	Chlorine	Chlorine	Chlorine
Chlorine	Chlorine	Chlorine	Chlorine
	Chlorine	Chlorine	Chlorine
			Chlorine
			Chlorine

If all the substances be studied in which the same elements unite in more than one proportion, it will be found that the numbers expressing the various combining weights of one element with a given quantity of another element are all multiples of some one number. These facts can be expressed in the form of the following law, known as the *Law of Multiple Proportions.*

When different weights of one element enter into combination with a fixed weight of another element, the different weights of the first element form simple ratios with each other.

175. Elements Often Exist in Compounds as Equal, Distinct, Separate Quantities.—In the preceding paragraphs it has been shown that the proportion, by weight, of oxygen and hydrogen is exactly twice as great in hydrogen dioxide as in water: moreover, that the oxygen acts as though half of it were not as well united to the hydrogen in hydrogen dioxide as the other half of the oxygen, since, on heating the hydrogen dioxide, half of the oxygen readily leaves the compound, and thus changes hydro-

gen dioxide into water. The other half of the oxygen clings more tightly to the hydrogen, and it therefore requires a much higher temperature to dissociate it from the hydrogen in water. Even at ordinary temperatures hydrogen dioxide slowly loses its oxygen, but above 200 degrees F. half of the oxygen passes off so readily that the liquid seems to boil briskly. In order actually to separate the oxygen from the hydrogen in water by means of heat, a much higher temperature, 1230 degrees to 1280 degrees Fahrenheit, must be applied to water after it has been changed to the form of steam.

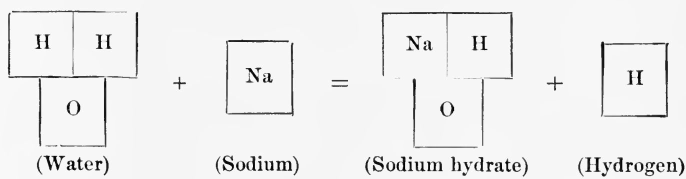
Since oxygen appears to exist in hydrogen dioxide in two quantities, not equally well united to the hydrogen, the question arises, may the oxygen in water be also separated into two or more distinct quantities so that part may be removed while the other remains in combination? No method for accomplishing this is known at present and chemists consider it impossible. Whenever any quantity of oxygen is set free, the proportionate quantity of hydrogen is also set free. The result is the complete breaking up of the water affected into its component elements. Only the water which has not yet lost its oxygen remains behind in the vessel.

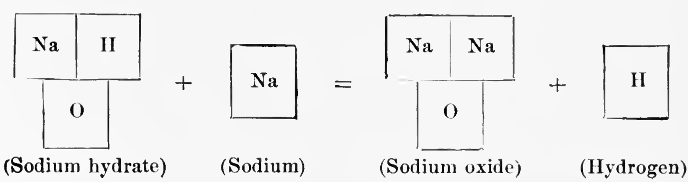
However, a method is known of separating a part of the hydrogen from water, leaving the rest in combination with the oxygen. In this case the part of the water affected loses exactly half of its hydrogen. In order to cause this separation heat is not sufficient. A chemical change is necessary. Some other element must take the place of that half of the hydrogen which was separated. One of the simplest means of accomplishing this is by placing sodium in a vessel containing a small quantity of water. Sodium takes the place of part of the hydrogen,

forming a new compound, sodium hydrate, while the hydrogen displaced escapes. If sodium is added until all of the water has been changed to sodium hydrate, or if, after some sodium has been added, the water not affected is removed by boiling, the new compound becomes visible. It is a white crystalline solid, and is usually sold under the name caustic soda. If this chemical is analyzed it is found that the proportion of hydrogen compared with oxygen is just half as great in sodium hydrate as in water. The other half of the hydrogen in water has been replaced by sodium.

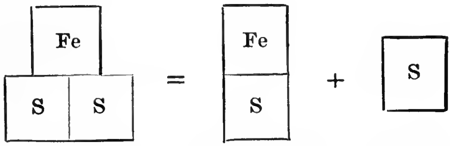
The removal of the second half of the hydrogen which was originally a part of the water, but which is now a part of the sodium hydrate, requires the application of heat. In this case 40 parts by weight of solid sodium hydrate should be heated with 23 parts of sodium. The hydrogen remaining as part of the sodium hydrate after the preceding experiment, then is also displaced by sodium, and the compound *sodium oxide* is formed.

These chemical changes may be represented as follows, designating the word sodium by the letters *Na*:





If iron pyrites is heated for a long time at a high temperature in a covered crucible, half of the sulphur is driven off and the compound iron sulphide remains. This may be represented diagrammatically as follows, the word iron being represented by *Fe*:



(Iron pyrites) (Iron sulphide) (Sulphur)

As the result of many similar experiments it has been learned that in many compounds one or more of the elements seem to exist as though in equal, distinct, and separable quantities; as though in water there were two equal, separable quantities of hydrogen and one inseparable quantity of oxygen, and as though in hydrogen dioxide there were two equal, separable quantities of hydrogen and two equal, separable quantities of oxygen.

176. The Molecules of Compounds Must Have the Same Chemical Composition as the Compounds Themselves.—Our conception of molecules demands that molecules of the same substance be considered exactly alike in every respect. The fact that crystals of the same substance have the same form, indicates that the molecules also of these substances are alike in *size* and *form* (§§ 86, 87). Since the same substances always consist of the same elements, combined in the same proportion (§ 173), their molecules must all be alike in *chemical composition.*

If the red oxide of mercury consists of mercury and oxygen in the proportion, by weight, of 12.5 to 1 (§ 173), then each single molecule of this substance also consists of mercury and oxygen united in this same proportion.

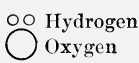
Moreover, whenever any element in any compound seems to act as if it consisted of several equal, distinct, and separable quantities (§ 175), it may be assumed that in each molecule of the compound this element consists of the same number of equal, separable quantities.

For example, it may be assumed that in the case of a molecule of water, there are two equal, distinct, and separable quantities of hydrogen but only one distinct quantity of oxygen.

Finally, since these equal quantities of the element entering into combination seem to be indivisible into still smaller quantities, it may be assumed that in the case of each molecule also the equal, distinct, separable quantities of this element are not further divisible.

In the case of water, this theory assumes that each molecule consists of two equal, distinct, separable quantities of hydrogen, which are not further divisible into smaller portions, but that there is only one such quantity of oxygen.

177. **Atoms.**—To the smallest, indivisible quantity of an element present in any molecule the name *atom* has been given. A molecule of water is therefore supposed to consist of 2 atoms of hydrogen and 1 atom of oxygen, while a molecule of hydrogen dioxide consists of 2 atoms of hydrogen and 2 atoms of oxygen:



Every element is believed to have its own kind of atom. The atoms of the same element are all alike, having the same size, shape and weight, but the atoms of different elements are unlike. Thus every atom of oxygen is like every other atom of oxygen, but not like the atoms of any

other element. There are then as many different kinds of atoms as there are elements.

Atoms have an attraction for each other, which causes them to unite and to form molecules. This force of attraction which brings the atoms together is called *chemical affinity*. Molecules may be considered as consisting of groups of atoms held together by chemical affinity.

178. Chemical Changes Involving Large Quantities of a Substance may be Discussed as if Affecting only One Molecule.—Since a molecule is nothing more nor less than the smallest particle of any substance which can exist, it is evident that no chemical change can take place in a body unless the chemical character of the individual molecules is altered. If the experiment is conducted in such a manner that only a part of the molecules of the compound are affected, then, at the close of the chemical operation, two compounds will be present: the unchanged portion of the original compound, and as much of the new compound as resulted from the chemical alteration of that part of the original substance which was actually affected. For the sake of simplicity, in order to make clear the general principles underlying chemical changes, it is always assumed that in each case under discussion the process involved has been carried far enough to affect every molecule. This being the case, the chemical changes affecting the entire mass of the substance acted upon are represented in miniature by the chemical changes taking place in any one of the molecules. In discussing chemical changes it is therefore usually convenient to discuss them as if affecting only one molecule of each substance acted upon.

179. Multiple Proportions Explained by Existence of Atoms.—The theory that elements are not more or less

continuous substances but are made up of separate atoms will explain a number of facts otherwise inexplainable. It may be shown by chemical analysis that the same compound always consists of the same elements united in the same proportion. Water, for instance, consists of hydrogen and oxygen united in the proportion of 2 parts of hydrogen to 16 parts of oxygen. According to the atomic theory each molecule of water consists of two atoms of hydrogen and one atom of oxygen, the oxygen atom weighing 16 times as much as one of the hydrogen atoms. Since each atom of oxygen is like every other atom of oxygen, and since each atom of hydrogen is like every other atom of hydrogen, the relative amount of oxygen and hydrogen in each molecule of water must always be the same.

Oxygen may unite with hydrogen in another proportion, differing from that present in water. It is evident, however, that if the second compound differs from the first compound only in the relative amount of oxygen present, each molecule of the second compound must contain more than one atom of oxygen. It cannot contain a fractional quantity of oxygen, since atoms are indivisible. This second compound is hydrogen dioxide. Its molecules consist of 2 atoms of hydrogen and 2 atoms of oxygen. Whenever one of the atoms of oxygen is driven off by heat, a molecule of water is left behind.

Oxygen unites in more than one proportion also with many other elements. It unites in 5 proportions with the same weight of nitrogen producing 5 different compounds. Since a molecule represents in miniature what is true of the entire mass of a compound, the number of atoms of nitrogen may be considered the same in every molecule of all five compounds. In this case, however,

the number of atoms of oxygen present in the molecules of the different compounds cannot be the same. The conception of atoms of the same substance as equal and indivisible excludes all possibility of the extrance of an element into combination except in the form of entire atoms. Therefore the number of atoms of oxygen present in the molecules of each of these five compounds must be 1, 2, 3, 4, or some other whole number of atoms.

According to chemists the number of atoms of nitrogen present in the molecules of all of these compounds is 2. With these two atoms of nitrogen are united 1, 2, 3, 4, and 5 atoms of oxygen. Therefore, the relative weight of oxygen united with nitrogen in these five compounds must be 1, 2, 3, 4, and 5 times the relative weight shown by that compound whose molecules contain only one atom of oxygen.

180. The Weights of the Atoms of Elements Compared with the Weight of an Atom of Hydrogen.—It is impossible to determine the actual weight of an atom, but if our ideas as to the number of atoms in various compounds are correct, it is possible at least to determine their *relative* weights; in other words, to determine how much greater the weight of one kind of atom is than the weight of another kind of atom.

In determining the relative weights, or what are believed to be the relative weights, of atoms, the weight of one atom of hydrogen, which is considered the lightest atom, has been taken as a standard. The weight of an atom of hydrogen is, therefore, called 1, and the weights of all other kinds of atoms are compared with this unit (§ 182).

It is known that in the formation of hydrochloric acid 1 part, by weight, of hydrogen unites with 35.2 parts, by

weight, of chlorine. If the theory accepted by chemists be true that a molecule of this acid consists of 1 atom of hydrogen and 1 atom of chlorine, then, if the weight of one atom of hydrogen be called 1, the weight of 1 atom of chlorine must be 35.2.

In the formation of water 1 part, by weight, of hydrogen unites with 8 parts, by weight, of oxygen. If it be true that water consists of 2 atoms of hydrogen and 1 atom of oxygen, then 1 atom of oxygen weighs 8 times as much as 2 atoms of hydrogen, or 16 times as much as 1 atom of hydrogen.

In ammonia gas $4\frac{2}{3}$ parts by weight of nitrogen unite with 1 part by weight of hydrogen. If the molecule of ammonia consists of 1 atom of nitrogen and 3 atoms of hydrogen, then 1 atom of nitrogen weighs $4\frac{2}{3}$ times as much as 3 atoms of hydrogen, or 14 times as much as 1 atom of hydrogen.

This discussion will be sufficient to show that if our ideas about the number of atoms in the molecules of various compounds are correct, it is possible to compare the weights of the atoms united in the same compound, and, by a series of comparisons, to compare the weight of any atom with the weight of the atom of hydrogen. The determination of the number of atoms in a compound is a matter of theory. The reasoning involved is often too difficult for an elementary text-book. Enough has been said in preceding paragraphs to give some notions on this subject (§§ 174—179).

181. Names of Elements Represented by Symbols.—In the discussion of chemical phenomena it is often convenient to be able to represent the names of elements by one or two letters. Some names are represented by the initial letter, capitalized always. Carbon is represented by C,

hydrogen by H, nitrogen by N, oxygen by O, phosphorus by P, sulphur by S. When several names begin with the same letter, two letters are used, the initial letter together with a letter occurring later in the word. The first letter is capitalized and the second is not. Aluminum is represented by Al, arsenic by As, chlorine by Cl, manganese by Mn, nickel by Ni, platinum by Pt, zinc by Zn. In selecting these letters the Latin names of the elements are used. For that reason the letters used to represent the names of some elements will not be recognized at once by those not familiar with the Latin names. For example, antimony (stibium in Latin) is represented by Sb, copper (cuprum) by Cu, gold (aurum) by Au, iron (ferrum) by Fe, lead (plumbum) by Pb, mercury (hydrargyrum) by Hg, potassium [kalium] by K, silver [argentum] by Ag, sodium [natrium] by Na, and tin [stannum] by Sn. The letters are called symbols of the elements.

182. Table of Elements, Including Their Symbols and Atomic Weights.—The following is a list of the more common elements. The names of the metals [§ 187] are in italics. The non-metals [§ 187] are printed in ordinary type. The symbols are given in the second and the atomic weight in the third column. A few substances act both as metals and as non-metals.

Name	Symbol	Atomic Wt.	Name	Symbol	Atomic Wt.
Aluminum	Al	27.0	Chlorine	Cl	35.2
Antimony	Sb	119.0	*Chromium*	Cr	51.7
Arsenic	As	74.4	*Cobalt*	Co	58.6
Barium	Ba	136.4	*Copper*	Cu	63.0
Bismuth ?	Bi	206.5	Fluorine	F	19.0
Bromine	Br	79.4	*Gold*	Au	196.0
Cadmium	Cd	111.4	Hydrogen	H	1.0
Calcium	Ca	40.0	Iodine	I	126.0
Carbon	C	12.0	*Iridium*	Ir	192.7

Name	Symbol	Atomic Wt.	Name	Symbol	Atomic Wt.
Iron	Fe	55.6	*Platinum*	Pt	193.6
Lead	Pb	205.4	*Potassium*	K	39.0
Lithium	Li	7.0	Silicon	Si	28.2
Magnesium	Mg	24.0	*Silver*	Ag	107.1
Manganese	Mn	55.0	*Sodium*	Na	23.0
Mercury	Hg	198.5	*Strontium*	Sr	87.0
Nickel	Ni	58.2	Sulphur	S	32.0
Nitrogen	N	14.0	*Tin*	Sn	118.0
Oxygen	O	15.8	*Zinc*	Zn	65.0
Phosphorus	P	30.8			

183. The Formula of a Compound Records the Number of Atoms of each Element Supposed to be Present in each Molecule.—The ability to represent a long name by means of a few letters is of great convenience, not only when it is necessary to use the names of elements, but also when it is desirable to use names of chemical compounds. In the system in actual use no attempt is made to abbreviate the names of compounds, but a combination of letters is chosen which will indicate, at a glance, what is believed to be the chemical composition of each *molecule* of the compound. This combination of letters is called the *formula of the molecule.* In these formulas each symbol represents a single atom of one of the component elements. For instance, red oxide of mercury is represented by the formula HgO, which indicates that every molecule of the red oxide of mercury is believed to contain one atom of mercury and one atom of oxygen.

When more than 1 atom of the element are present, a number, which indicates how many atoms of the element are present in the molecule, is written at the lower right-hand corner of the symbol representing the element. The formula of water, H_2O, indicates that 2 atoms of hydrogen and 1 of oxygen are present in each molecule of water.

In the same manner, a single molecule of potassium chlorate may be represented by the formula $KClO_3$. This indicates that each molecule of the substance contains 1 atom of potassium, 1 atom of chlorine, and 3 atoms of oxygen.

A group of letters enclosed in brackets, with a small number after the second bracket, indicates that the entire group of atoms represented by the letters enclosed in the brackets must be multiplied by this number in order to ascertain the number of atoms of each element in the molecule of the compound. Thus $Pb(NO_3)_2$, lead nitrate, consists of 1 atom of lead, 2 of nitrogen, and 6 of oxygen. In this case the group of atoms in that part of the formula which is enclosed in brackets is believed to be more strongly united than the other atoms, so that in cases of substitution it often enters and leaves the molecule as a group. At least the atoms included in the group often enter the molecule from the same source. Thus the NO_3 of lead nitrate may have been derived from nitric acid, the hydrogen of the acid having been displaced by lead. When it is desirable to express that several molecules are present, a large figure representing the number of molecules is placed before the formula. Thus, $3H_2O$ represents 3 molecules of water.

184. How to Read a Formula.—A glance at a formula will at once suggest to the expert chemist the name of the compound; moreover, it will also suggest, even to one not an expert chemist, the chemical composition of the compound. In speaking of, or in writing about a substance, it is often more convenient to give the formula of its molecule than to use its actual name. In this case each figure and letter is read in the order in which it occurs in the formula. A slight stop is made after every

figure indicating the number of atoms. Any figure given before any of the letters of the formula have been mentioned is at once understood as giving the number of molecules present. The reading of $3H_2SO_4$ is three—H two—S—O four, and $4K_2Cr_2O_7$ is read four—K two—Cr two—O seven.

Read the formulas, P_2O_5, CO_2, $KClO_3$, $Ca\ CO_3$, $ZnSO_4$. In every case tell what elements and how many of their atoms are present in each molecule.

185. The Formula of a Compound Indirectly Records the Relative Combining Weights of the Component Elements.—The existence of both molecules and atoms is assumed in order to explain phenomena, often very familiar phenomena, which otherwise are inexplainable. Since it is not at all likely that molecules and atoms will ever be seen, our ideas of them and of their properties must necessarily vary with the increase of facts which we try to explain when we assume the existence of molecules and atoms. As our knowledge of chemistry increases it is fair to assume that new methods of experimentation may prove that elements which we now consider to be present in molecules in the form of single atoms, may in reality be represented by 2 or 3 atoms, or that elements now believed to be present in the form of 2 atoms in each molecule may later, on account of further discoveries, be believed to be present in the form of 4 or 6 atoms in each molecule, so that it will be necessary from time to time to change some of the formulas in order to represent the new facts.

However, while our conceptions of the number of atoms of each element in the molecules of various compounds may change, there is one fact which can be determined with considerable exactness, regarding which there are

likely to be few changes of opinion in the future, and that is the *relative quantity of each element present in a compound.* If the element has been accurately identified, if the balances are good, and if the chemical changes taking place during all the processes of synthesis and analysis have been correctly followed, there need be little change of opinion as to the relative weights of the elements present.

In the effort to express the atomic constitution of each molecule of the compound, the relative quantity of each element present in the compound is also expressed, although only indirectly. For instance, if the formula of nitric acid is written as HNO_3, this shows that, at present, methods of chemical analysis suggest that 1 atom of hydrogen, 1 of nitrogen and 3 of oxygen are present in the compound. Since at present the weight of an atom of nitrogen is assumed to be 14 times as great as the weight of an atom of hydrogen, and that of an atom of oxygen to be 16 times as great as that of an atom of hydrogen, it is evident that the relative proportions of hydrogen, nitrogen, and oxygen present in nitric acid must be 1:14:48. This relative proportion of the three elements in nitric acid is known with certainty. It has been determined by chemical analysis. But the existence of three atoms of oxygen, with only one atom of hydrogen and nitrogen in this compound, is merely an assumption (Fig. 86), based, however, upon facts which are just as well established as those discussed in the previous paragraphs in connection with the constitution of water and of hydrogen dioxide.

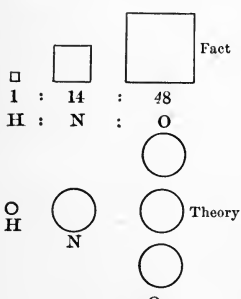


FIG. 86.

From the relative proportions of the elements present in a compound, as established by actual analysis, and indirectly recorded in the formula for a molecule of a compound, it is possible to determine what weight of any element is present in any compound. If, for instance, in the case of nitric acid, the elements hydrogen, nitrogen, and oxygen are present in the proportions 1 : 14 : 48, then $\frac{1}{63}$ of any quantity of nitric acid must be hydrogen, $\frac{14}{63}$ must be nitrogen, and $\frac{48}{63}$ must be oxygen. In 16 ounces of nitric acid, $\frac{1}{63}$ of $16 = .254$ ounce of the acid must consist of hydrogen, $\frac{14}{63}$ of $16 = 3.556$ ounces of the acid must consist of nitrogen, and $\frac{48}{63}$ of $16 = 12.190$ ounces of the acid must consist of oxygen.

In fact, before a single formula is ever written, some chemist analyzes the compound and determines the relative proportion by weight of all the elements which it contains. These relative proportions of the elements he records in his formula, but, instead of writing his formula in the form of .254H, 3.556N, 190O, or 1H, 14N, 48O, he attempts to express the results of his analysis in such a manner that their application may be general. He therefore determines from his chemical analysis how many atoms of each element are present in each molecule and records the number of atoms in the formula. Then the number of atoms of the various elements as recorded in the formula indicates practically also the relative proportion by weight of the elements present, to any one who knows the relative weights of the different atoms.

186. Chemical Changes May Be Recorded in the Form of an Equation.—The amount of each element present in any particular quantity of any substance may be determined by chemical analysis. Since not a particle of substance is either created or destroyed during any chemical

change, it is possible to express *in the form of an equation* the relative amount of each element present in each substance at the beginning of the experiment and in what manner these elements are combined in the different products resulting from the chemical change.

In practice, no attempt is made to express in equations the actual weight of the different materials taking part, but only their relative weights. This may be accomplished by representing the chemical change as though it were taking place between only 1, 2, or some other small number of molecules of the substances present. The manner in which the atoms are united *before* the chemical change is indicated before the equality sign. The manner in which the atoms are united *after* the chemical change is indicated after the sign of equality. In other words, the substances used are indicated on the left of the sign of equality, and the substances resulting from the chemical action are indicated on the right of this sign.

To illustrate, the chemical action which took place when the potassium chlorate was heated together with the manganese dioxide (§ 134), may be represented by

$$KClO_3 + MnO_2 = KCl + 3O + MnO_2,$$

which means that after the chemical change took place the manganese dioxide was found unchanged, but the potassium chlorate was found broken up into potassium chloride, KCl, and oxygen.

The chemical action when phosphorus is burned in air may be represented by the equation,

$$2P + 5O + 20N = P_2O_5 + 20N,$$

which means that, after the chemical change has taken place, the nitrogen in the air is found unchanged, but the

atoms of phosphorus and the atoms of oxygen have united in the proportion indicated.

187. Classification of Elements.—Elements are classified as metals and non-metals. The *metals* possess a peculiar lustre which we call metallic. They are good conductors of heat and electricity. When they are substituted for the hydrogen in acids, they form *salts.* When chemical action takes place between the oxide of a metal and water, a new compound called a *base* is produced.

The *non-metals* do not possess a metallic lustre. Most of them are very poor conductors of heat and electricity. When united with hydrogen, they generally form gaseous compounds. When chemical action takes place between the oxide of a non-metal and water, an *acid* is produced.

The most important metals and non-metals are given in the table in § 182.

The meaning of some of the terms used here are explained in the next section.

188. The Classification of Compounds.—No system of classification of compounds has been proposed, up to the present time, which can in any sense be called perfect. Nevertheless the classification now in use has been found to be very convenient.

The four most important classes are oxides, acids, bases, and salts.

An *oxide* is a combination of an element with oxygen. H_2O, CO_2, MnO_2.

An *acid* is a peculiar combination of hydrogen with one or more other elements. The combination is of such a character that the hydrogen may be more or less readily displaced by a metal, so that the hydrogen compound will be changed to a metal compound.

$$2HCl + Zn = ZnCl_2 + 2H.$$
$$H_2SO_4 + Mg = MgSO_4 + 2H.$$

Some acids are formed by the combination of hydrogen with only chlorine, bromine, iodine, or sulphur, but most acids are formed by the union of hydrogen with two or three elements, of which one is oxygen.

A *base* is formed by the union of a metal with one or more of the group of atoms OH, called hydroxyl. Those bases which contain the metals sodium, Na, potassium, K, or the group of atoms NH_4 are also called *alkalis*, Na(OH), K(OH). $NH_4(OH)$.

Acids and bases have several exactly opposite properties. Acids have an acid or sour taste; they change litmus-paper from blue to red. Bases have the taste of lye, or an alkaline taste, and they change litmus-paper from red to blue. Both acids and bases are chemically active substances, but, when they are brought in contact, they counteract each other, and, if the proportion be properly adjusted, they entirely destroy the characteristic properties of each other. They *neutralize* each other. In the neutralized solution the acid is no longer able to turn blue litmus-paper red, and the base cannot turn red litmus-paper blue. The reason for the inactivity of a neutral solution is the fact that in a neutral solution no acid or base is present. As soon as an acid and a base come in contact with each other, chemical action takes place, the metal of the base is interchanged with the hydrogen in the acid, and two new compounds are formed. One of these compounds is water. The other compound is a substance called a *salt*.

$$HCl + NaOH = NaCl + H_2O.$$

Salts may also be produced by chemical reactions in which no acids are present.

A salt has the properties of neither an acid nor a base.

It is a neutral substance. It has exactly the same composition as the acid from which it was derived, except that the hydrogen has been displaced by some metal. The name salt is given to this class of compounds, because most of these compounds, after having been dissolved in water, crystallize when the water is evaporated and the crystals of the great majority of chemical salts are transparent and colorless like table salt. A very considerable number of chemical salts, however, are beautifully and strongly colored.

189. Poisons and Antidotes.—Both acids and bases are usually poisonous, at least when taken in large quantities. If an acid has been swallowed, some base like baking soda or lime-water is given to neutralize the acid. If the substance swallowed be a base, some weak acid, like weak vinegar (acetic acid), will serve as an antidote. Different poisons require different antidotes, but the principle involved in securing an antidote to a chemical poison is usually to secure a chemical which, on entering into chemical combination with the poisonous substance, will form a harmless compound. Emetics and stomach-pumps serve to remove poisons from the stomach, and if used soon enough may rid the stomach of poison before much has been taken into the system.

190. Names of Compounds.—When oxygen, chlorine, bromine, iodine, sulphur, arsenic, carbon, all of which are non-metallic elements, unite with only one other element, and that element is a metal, the compound is called an oxide, chloride, bromide, iodide, sulphide, arsenide, or carbide of that metal. The metal is usually mentioned first. For instance, PbI_2 is lead iodide. If it be desirable to mention the number of atoms of the non-metallic element present in the compound, the following prefixes

are placed before the name of the non-metallic element: mono (one), di (two), tri (three), tetra (four), penta (five). For example, MnO_2 is manganese dioxide; PCl_3 is phosphorous trichloride. The prefix sesqui means one and a half. It is used when the ratio of the metal to the non-metal is 2 to 3 ($=1$ to $1\frac{1}{2}$). For instance, Mn_2O_3 is manganese sesquioxide.

When a non-metallic element unites with hydrogen to form an acid, the prefix *hydro* is used before the name of this non-metallic element. For instance, HCl is hydrochloric acid.

When an acid consists of hydrogen, oxygen, and some other element, this other element gives the name to the acid and the name ends in *ic*. For instance, HNO_3 is nitric acid.

If two acids are formed by the same elements, and the number of atoms of oxygen as compared with the number of atoms of the other two elements is not the same, the name of the acid which contains the smaller quantity of oxygen ends in *ous*. For example, H_2SO_4 is sulphuric acid; H_2SO_3, sulphurous acid.

When three elements unite to form three acids, each with a different number of atoms of oxygen in the molecule, the one containing the least oxygen has the prefix *hypo* and the ending *ous* attached to the name of the acid. For instance, H_3PO_4 is phosphoric acid; H_3PO_3, phosphorous acid; and H_3PO_2, hypophosphorous acid.

Salts produced by the substitution of a metal for the hydrogen in an acid are named by using both the name of the metal and the name of the acid. But if the name of the acid ends in *ic*, the name of the salt ends in *ate*, and if the name of the acid ends in *ous*, the name of the salt ends in *ite*. For instance, KNO_3 is potassium ni-

trate; KNO_2, potassium nitrite; $BaSO_4$, barium sulphate; $BaSO_3$, barium sulphite. The connection between the name of a salt and that of the acid from which it was derived is indicated in the following table:

HNO_3	+	KOH	=	KNO_3	+	H_2O.
Nitric Acid				Potassium Nitrate		
HNO_2	+	KOH	=	KNO_2	+	H_2O.
Nitrous Acid				Potassium Nitrite		
H_2SO_4	+	$BaCl_2$	=	$BaSO_4$	+	$2HCl$.
Sulphuric Acid				Barium Sulphate		
H_2SO_3	+	$BaCl_2$	=	$BaSO_3$	+	$2HCl$.
Sulphurous Acid				Barium Sulphite		

The endings *ic* and *ous* appended to the names of the metals in the names of compounds call attention also to the quantity of oxygen, chlorine, or non-metal present. For instance, Fe_2O_3 is ferric oxide; FeO, ferrous oxide; $FeCl_3$, ferric chloride; $FeCl_2$, ferrous chloride; $Fe_2(SO_4)_3$ ferric sulphate; $Fe_2(SO_4)_2$, ferrous sulphate.

191. Chemical Action Assisted by the Presence of Water. —Chemical action does not take place between lead nitrate and potassium iodide (§ 171) while they are in the solid state. Even if they are ground together and intimately mixed, they do not combine. Each particle of solid material is held together by the force of cohesion, and, before chemical action can take place, this cohesion must be overcome. Dissolving a solid in water loosens the cohesion between the molecules; more than that, it weakens the force with which atoms hold together in the molecule. The result is that chemical action will often take place readily between solids dissolved in water, even in cases in which no chemical action can be noticed when these solids are mingled in the solid state.

192. Chemical Action Assisted by Heat.—Increase of heat causes the molecules of a solid to move farther apart. Not only is the cohesion between the molecules lessened, but also the force with which the atoms in each molecule cling together is weakened. In this condition atoms can enter more readily into combination with other atoms. When gunpowder is heated beyond a certain temperature, chemical action between the various solids used takes place with such violence that an explosion occurs.

Chemical action between solids in solution also is very much increased by heating the solution.

193. Heat is Consumed during the Separation of Compounds into Their Elements or Components.—It has been shown that increase of heat causes molecules to move farther apart. This is true not only in cases where there is no change of state (solids, § 63; liquids, § 62; and gases, §§ 97, 115), but also in all cases of change of state from liquids to gases (§§ 96, 104), and in most of the cases of change from solids to liquids (§§ 95, 104). The same fact may be stated in another form by saying that heat is consumed during the separation of molecules. When the molecules of solids separate on dissolving in a liquid, heat is consumed, and, since the heat is usually taken by the solid in large part from the liquid in which it dissolves, the liquid gets colder (§ 114). When the molecules of liquids separate during evaporation, heat is consumed. This heat is secured chiefly from the air into which the liquid evaporates. In consequence, the air becomes colder (§ 113).

According to the same principle increase of heat causes a separation of atoms (§§ 134, 154) already in combination as molecules, and conversely the separation of atoms from their combinations as molecules consumes heat.

194. When Substances Unite to Form Compounds Heat is Produced.—It has been shown that, when gases return to a liquid state, or when liquids return to a solid state, heat is given out although there is no fall in temperature (§§ 111, 112). It is also a matter of common experience that hot solids and liquids give out heat, when they themselves are cooling or lowering in temperature. Experiments have been devised to show that, while substances in solution are crystallizing, they give up heat to the water in which they are dissolved or that the temperature of the water rises.

From these facts the general rule may be made, that, while the molecules of substances come closer together, they give up heat to surrounding bodies. The unusual behavior of water has so far not been explained (§ 117).

The coming together of atoms so as to form molecules also produces heat. When elements unite very slowly or in small quantities at any one time, the heat produced may pass off into the air so readily that it may not even be noticed. However, when the chemical action is rapid, the production of heat can be detected readily. When water is poured upon a piece of recently burned quicklime, the two substances unite to form slaked lime [$CaO + H_2O = Ca(OH)_2$] and the heat produced is considerable. This action may be seen whenever men slake lime to make mortar. Fires are frequently started when water gains access to ships or warehouses in which quicklime is stored.

195. Heat may be Produced with Sufficient Rapidity to Cause Light.—In some cases the chemical combination is sufficiently rapid to cause light in addition to heat. Straighten a piece of watch spring. Heat the tip red hot and dip it into sulphur powder. As soon as the sulphur

adhering to the spring has ignited, dip the spring quickly into a jar of oxygen. The iron will unite with the oxygen, and sufficient heat will be produced to give rise to a brilliant sputtering light. In fact the light caused by the ordinary burning of objects in air is due merely to the great heat produced by the union of oxygen with the elements in the burning material. Ordinary combustion is, therefore, due to rapid union of the elements in burning bodies with the oxygen in the air.

Slow combustion is vastly more common than ordinary combustion, but it often passes unnoticed. Most of the chemical unions that take place in nature and even many of those which take place in the laboratory, take place without the production of light. In many of these cases oxygen is one of the uniting elements. The uniting of oxygen with other elements is called *oxidation*.

196. The Origin of Heat in the Animal Body.—One of the most important cases of slow combustion is that which is the cause of the heat in the animal body. The heat-yielding food-stuffs that enter the body are compounds which always contain carbon, hydrogen, and oxygen (fat, sugar, starch, vegetables, etc.) and often also nitrogen (meat). The materials of which our body is composed consist of the same elements. When the compounds in our body are decomposed they unite with the oxygen brought in through our lungs and circulating through our blood. The result is that the decomposition of the compounds in our body is accompanied by a slow combustion due to the union of oxygen with the elements which formed part of these compounds.

Animal heat is not due to the decomposition of the chemical compounds in our bodies, since the separation of atoms, which takes place during decomposition, is

accompanied by absorption, not by emission of heat. But the heat given out as the result of the union of additional oxygen to the decomposition products, is so much greater than the heat absorbed during the separation of the atoms in decomposition, that on the whole more heat is given out than taken up and the heat given out serves to warm the animal body.

CHAPTER V

SOUND

197. Sound Produced by Vibrations.—Every body which produces sound is in motion. When a tuning-fork, violin, or bell produces sound, if the hand touches lightly the prong of the tuning-fork, the string of the violin, or the margin of the bell, the motion may be distinctly felt. If a light pith-ball suspended at the end of a thread is brought into contact with these sounding bodies (Fig. 87), it flies off, returns, and flies off again, as if repeatedly struck. The parts in motion move short distances only. On this account the motion is often not visible to the eye.

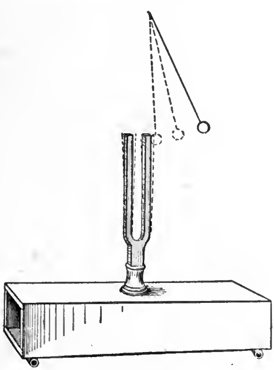


FIG. 87.

The parts in motion move to and fro like the pendulum of a clock, but with greater frequency. Even the least frequent of these to and fro motions amount to at least sixteen and a half per second. This frequency makes the individual motions imperceptible, even if the distance covered is great enough to be visible to the eye. But the hazy effect produced by these rapid motions can be distinctly noticed.

198. The To and Fro Motions are Called Vibrations.—The to and fro motions are called vibrations. An entire vibration includes both the to and the fro motion. The mo-

tion in one direction only, from the farthest point reached in the right to the farthest point in the left, is but half of a vibration (Fig. 88). Half of the motion from one side to the other is called the *amplitude* of vibration. The amount of time taken by the body to complete an entire vibration is called the *period* of the vibration. The number of vibrations completed by the body during one second is called the *frequency* of the vibrations. When two or three bodies complete the same number of vibrations per second, but move with varying degrees of rapidity, so that some produce vibrations with great amplitudes, and other vibrations with smaller amplitudes, the vibrations are said to vary in violence or *intensity*.

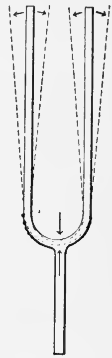


FIG. 88.

199. The Frequency of the Vibration Determines the Pitch of the Tone.—If a sounding body vibrates a few times per second, it will give a low tone. If it vibrates many times per second, it will give a high tone. The lowness or highness of a tone is called the *pitch* of the tone. The frequency of the vibrations of a sounding body, therefore, determines the pitch of the tone which it produces.

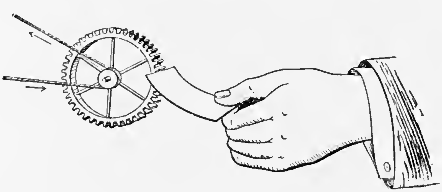


FIG. 89.

This may be shown easily by a simple experiment. If a stiff piece of card-board is held against the cogs of a rapidly turning wheel (Fig. 89) taken from the interior of some clock, the card-board snaps from cog to cog, being first lifted slightly by one cog, and then allowed to slip past

its end so as to strike the next cog. This causes the end of the card-board to move up and down or to vibrate. As long as the wheel moves slowly only a succession of snaps is heard, but as soon as the motion is sufficiently rapid to cause the card-board to snap from cog to cog at the rate of about 16 times per second, a very low tone is heard in addition to the snaps. As the motion of the wheel is increased, the vibrations produced by the card-board are more frequent, and the tone heard in addition to the snaps is not only louder but also higher in pitch. If the wheel be rotated with sufficient frequency, the pitch may rise high enough to be disagreeable.

200. The Frequency of Vibration of Various Tones.—The lowest C of the pipe organ is produced by $16\frac{1}{2}$ vibrations per second, the lowest A of the grand piano by $27\frac{1}{2}$ vibrations per second, the lowest C of the ordinary piano by 33 vibrations, and the lowest E of the double bass violin by $41\frac{1}{4}$ vibrations. The highest C of the piano is produced by 4224 vibrations per second, and the highest D of the piccolo flute by 4752 vibrations per second. Tones produced by vibrations more rapid than 4752 per second are not considered useful for musical purposes, although vibrations as frequent as 40,960 per second can be heard.

The lowest tones which are audible to the ear are used in music (pipe organ), although it is questionable whether they have any distinct musical quality when the vibrations number less than 32 per second.

The frequency of vibration of a mosquito's wings can be determined by increasing the speed of the wheel of the clock, until the card-board held against the cogs gives out a sound of equal pitch. From the number of cogs in the wheel and the number of turns per second,

the number of vibrations of the card can be determined. Since the wings of the mosquito give the same tone as that given by the card, the number of vibrations of the wings of the mosquito must be the same as the number of vibrations of the card.

In the same manner, the number of vibrations produced by the vocal cords in the throat of a man or woman singing can be determined. The tone of G written on the lowest line of the bass staff is produced by 96 vibrations per second, middle C by 256 vibrations, and F, written on the highest line of the soprano staff, by 682.6 vibrations. It is possible to sing both lower and higher than these tones. C above the soprano staff is produced by 1024 vibrations per second.

201. A Medium is Necessary to Transmit the Vibrations of the Sounding Body to the Ear.—Since the instrument producing the sound and the ear perceiving the sound are always at some distance from one another, something must act as a means of transmission between the instrument and the ear. This medium is usually the air.

An alarm clock placed under a bell-jar on the plate of an air-pump can be heard easily, but if the air is pumped out from the space within the bell-jar, the sound is much less distinct. The sound could not be heard at all, if its transmission through the plate of the air-pump could in some way be prevented. A considerable quantity of cotton batting placed under the clock will practically accomplish this (Fig. 90).

Water also may serve as a medium. If the head is held under water while some one, a moderate distance away, pounds together two stones, also held beneath the surface of the water, the water transmits the sound so effectively that the sensation is sometimes even painful.

Even solids transmit sound. In fact, some solids transmit sound better than air. If the point of a pin is scratched lightly against one end of a long wooden pole, the sound can be heard easily by a person who places his ear against the other end. However, if the ear is held at some distance away from the pole, but at the same distance from the scratched end as before, the sound, in this case transmitted through the air, may not be audible. The cannonading at Antwerp in 1832 was heard in the mines of Saxony 320 miles away. What transmitted the sound?

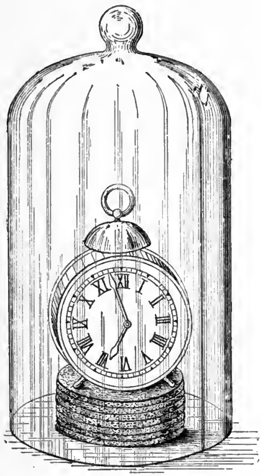


FIG. 90.

202. The Sensation of Sound.— The original cause of sound and the physiological effect of sound are two widely distinct things. The original cause of sound is the vibration of the whole or of a part of some musical instrument or other body. The physiological effect of sound is the sensation produced by these vibrations on the nerves of the ear (auditory nerves). The physicist studies the original cause of sound, how sound is transmitted from the original sounding body to the ear, and the character of the action of the various mechanisms which transmit the vibrations from the air to the nerves of the ear (fibres of the basilar membrane, §§ 214–215). The physiologist dissects all parts of the organ of hearing and studies the effect produced by the vibrations upon the auditory nerves.

If there is no air present to transmit these vibrations,

if there is no ear present to receive them, or if the vibrations are too weak to affect the ear, there will be no sensation of sound. *Loudness* of sound is the intensity of the sensation produced in the nerves of the ear. Any cause which will decrease the intensity of the vibrations from the time when they leave the sounding body to the time when they reach the nerves in the ear, produces a corresponding decrease in the loudness or strength of the sensation in the auditory nerves.

203. Sound Transmitted through the Air by Waves of Condensation and Rarefaction.—When the prong of a tuning-fork moves forward, it condenses the air immediately in front of the prong, and, as the molecules strike against molecules, this condition of condensation travels forward and away from the fork. When the prong swings back during the second half of its vibration, it tends to leave a vacuum on the side where a moment before it had produced a condensation. As the nearest air particles rush back to fill up this space, a condition of rarefaction occurs at the points more remote from the fork, from which the air particles have returned. This *condition of rarefaction* is taken up successively at points more and more removed, so that, while the molecules of the air are in reality moving *back* towards the fork, the condition of rarefaction may be said to be spreading *outward* from the fork. Therefore, both the condition of condensation and that of rarefaction travel outward from the fork.

If the fork continues to vibrate for some time, there will be a regular succession of these condensations and rarefactions moving away from the fork. Since the condensations are produced by the forward motion of the fork and the rarefactions by the backward motion, the rarefactions will always be found between the condensations.

At any given time the condensations first formed will have reached points in the air more distant from the fork, while the condensations or rarefactions later formed will not have travelled so great a distance (Fig. 91).

If the rate of vibrations given out by the tuning-fork be rapid, the distances from condensation to condensation will be short. If the rate of vibrations be slow, the distances between successive condensations will be greater. As long as the rate of vibration remains the same, the distances between successive condensations will be equal.

When the air is condensed at any point, it spreads away from that point to all regions where the pressure is

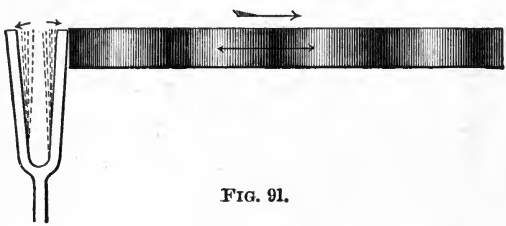


FIG. 91.

less. The result is that the waves of condensation, as they leave the fork, spread in all directions and form a succession of spherical shells, the alternating shells being represented by alternating conditions of condensation and rarefaction (Fig. 92).

If an attempt be made to compare the series of condensations and rarefactions to something which may be actually seen in nature, no better object of comparison can be found than the succession of concentric crests and hollows which move away from the point where a stone is dropped into water. For this reason, the successive condensations and rarefactions produced in the air by sounding bodies are usually referred to as waves of sound.

204. Although the Vibratory Motion is Transmitted through the Air for Long Distances, the Individual Molecules of Air Move Only Short Distances.—A very crude notion of the action of the molecules during the transmission of sound may be secured from the following experiments:

If a dozen boys facing in the same direction form a line,

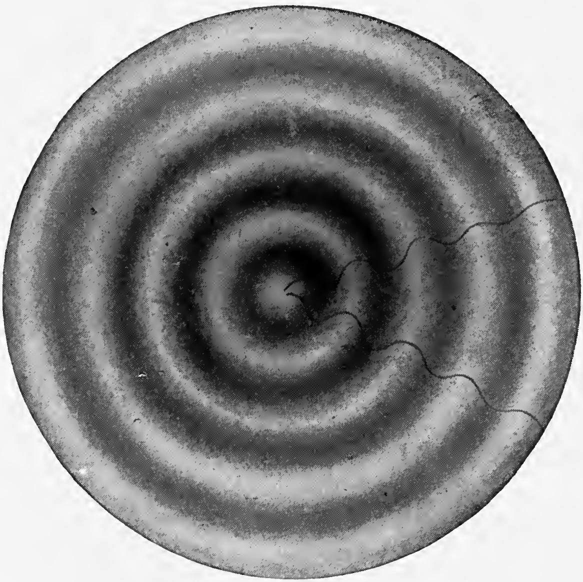


FIG. 92.

each boy placing his hands firmly against the shoulders of the boy in front, a strong push against the boy in the rear of the line causes the boy at the front to topple over (Fig. 93). The motion is communicated from boy to boy. The distance along which the motion is transferred is much greater than the distance passed over by any one boy.

If a large stone be dropped into a pond, a series of waves will travel away from the stone to the margin of the pond. Any corks floating upon the water, however, will merely bob up and down as the waves pass beneath them and move slightly forward and backward without being carried permanently nearer the shore. It is evident that waves have been formed in the water without any considerable forward motion on the part of the individual molecules of water which transmit the waves.

In the same manner a molecule of air set in motion by the prong of a tuning fork may strike against the molecule in front, this molecule may strike against the next molecule, and thus the motion may be transferred for great distances from molecule to molecule without involving any great amount of motion on the part of any one molecule.

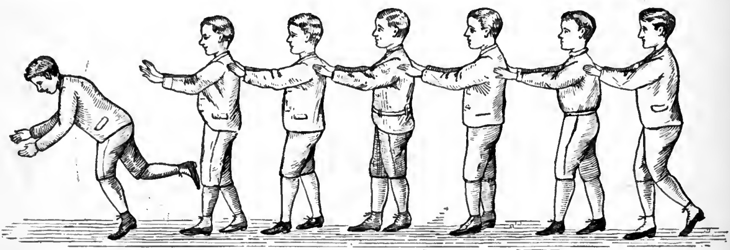


FIG. 93.

205. The Vibrations of the Sounding Body Cause the Individual Molecules of Air to Vibrate.—A more exact notion of the method of transmission of sound through the air requires a study of the character of the motions of the individual molecules. When the prong of a tuning-fork moves forward, the molecules of air in front of the prong also move forward, and, as we have seen, the for-

ward motion is communicated from molecule to molecule, until the molecules at a considerable distance from the fork also move forward. When the prong of the tuning-fork returns to its original position, it tends to form a vacuum there where a moment before it produced a condensation. The pressure of the air in contact with this side of the prong is now less than the pressure at a greater distance from the fork. The molecules of air, which a moment ago were moving away from the fork, may now return. The molecules nearest the fork return first. This diminishes the pressure of the air in the space from which they return, and so the more distant molecules may also move backward. This motion is taken up by molecule after molecule, until even the molecules at a considerable distance from the fork have taken up the returning motion.

As the prongs of the tuning-fork continue to move forward and backward, a corresponding forward and backward motion is taken up by all the molecules of the air. The molecules nearest the fork take up this motion first and the molecules at a greater distance take it up later. These to and fro motions are vibratory motions, and it is by means of such motions that sound travels through the air.

206. Loudness, or Intensity of Sound.—The intensity of the sensation produced in the ear depends not directly upon the intensity of the vibrations of the molecules in contact with the sounding body, but upon the intensity of the vibrations of those molecules which come in contact with the ear. If the molecules which come in contact with the ear do not vibrate strongly, the sound will be faint, even if the molecules in contact with the vibrating body are in violent motion. This, however, is always the

case when the ear is at a considerable distance from the sounding body.

When the air is condensed at any point, it spreads away from that point to all regions where the pressure is less. Therefore, the air condensed by the forward motion of the tuning-fork tends to spread in all directions. As the condition of condensation travels outward, it spreads over more and more space, and, therefore, the degree of condensation becomes less as the distance from the fork increases (Fig. 92). Since these condensations are produced by the vibrations of the molecules of the air, a lessening of the amount of condensation implies a lessening of the amount of space traversed by each molecule during its vibrations. Therefore, the intensity of the vibrations of the molecules of air decreases as the distance from the sounding body increases. The mathematical expression for this statement is that *the intensity of vibration varies inversely as the square of the distance.*

Anything which prevents the spreading of the condensations after they leave the sounding body will prevent, to a considerable extent, the loss in the intensity of vibration as the vibratory motion is transmitted from molecule to molecule. This principle is made use of in speaking-tubes.

In an indirect manner, of course, the intensity of the sensation of sound depends not only upon the distance from the sounding body but also upon the intensity of vibration of the molecules actually in contact with the sounding body, because, if these molecules do not vibrate strongly, the sound will be weak even at its source, and may be entirely inaudible at a short distance from the sounding body. This may be expressed by stating that *the intensity of the vibrations of the molecules in contact with*

the ear depends upon the intensity of vibration (amplitude of vibration) of the sounding body.

If only a few molecules of air are set in motion by the sounding body, their energy is soon lost in causing the neighboring molecules to vibrate. But if the number of molecules originally set in motion is very great, their vibrations will be transmitted much farther before they become too weak to affect the ear. Therefore, the intensity of vibration of the molecules in contact with the ear depends not only upon the distance of the ear from the sounding body and the intensity of vibration of the sounding body itself, but also upon the number of molecules of air set in motion by direct contact with the sounding body. If a tuning-fork is mounted upon a box not only is the small quantity of air in contact with the fork set in motion but also the much greater quantity in contact with the box, and the sound will be audible at a much greater distance.

These facts are often stated in the form of the following rules:

Loudness of sound varies inversely as the square of the distance.

Loudness varies with the amplitude of vibration of the sounding body.

Loudness varies with the area of the sounding body.

207. The Vibrating Air May Communicate Vibrations to Other Bodies.—Place two large tuning-forks, mounted on boxes and producing exactly the same tone, about 12 feet apart. Direct the open ends of the boxes toward each other. Strike one of the tuning-forks once or twice sharply with a leather mallet, so that for half a minute it gives out a loud sound. Then grasp the prongs of this fork with the hand quickly, so that the fork can no longer vibrate.

If the ear be held near the open end of the other box (Fig. 94), it will be noticed that the other tuning-fork has in some manner been set in vibration, although it has not been struck by any visible material.

The first tuning-fork causes the air in contact with it to vibrate. This vibratory motion is transmitted from molecule to molecule. When the molecules surrounding the second fork move forward, they push the prong very slightly in the same direction, and when a moment later the molecules move in the opposite direction, this prong of the tuning-fork is also allowed to return.

A single forward and backward motion of the air sur-

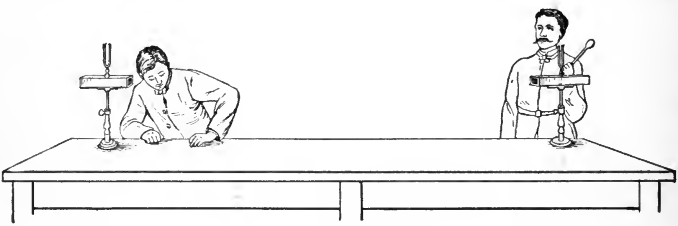


FIG. 94.

rounding the second fork does not make this fork vibrate sufficiently to produce an audible sound; but the accumulative effect caused by a regular succession of a large number of such vibratory motions will finally cause the second fork to vibrate sufficiently to produce a sound loud enough to be heard if the ear be placed near the fork.

It is highly essential that the two tuning-forks should produce the same tone; in other words, that they should vibrate at exactly the same rate. Otherwise, when the vibrating air is ready to return at the end of its first half-vibration, the prong of the tuning-fork may still be moving forward, and, when the molecules of air are ready to

go forward the second time, the fork may not have completed its first vibration. In this case there is not sufficient agreement between the vibrations of the air and the vibrations of the second fork to enable the air to set this fork in vibration effectively.

If a loud, clear note be sung in front of a piano with the dampers lifted from the wire (by the use of the loud pedal), the wire having the same pitch will for a short time give out the same tone.

When a body is made to vibrate by vibrations produced in the air by some other body, it is said to vibrate in sympathy with the other body, and the vibrations are called *sympathetic.*

208. Variations in the Pitch of Strings.—Any one who is familiar with the appearance of the interior of the grand piano knows that the wires of the piano vary in length and in thickness. Moreover, while some strings consist of a single wire, others are formed by wrapping a layer of wire around a thicker central wire in order to increase the weight. In a general way it may be stated that the short and thin wires produce the higher tones, and the long, thick or heavy wires produce the low tones. Anything which increases the weight of the wire lowers the tone. For this reason, the layers of wire are wrapped around the wires intended for bass tones. The more tightly a string is stretched, the higher is the tone which it produces.

209. The Number of Vibrations Varies Inversely as the Length of the String.—The number of vibrations which a string will produce in one second depends upon the length of the string. A string half as long as another will produce twice as many vibrations; one a third as long will produce three times as many vibrations; one a fourth as

long will produce four times as many; one three-fourths as long will produce four-thirds as many vibrations. The mathematical rule is that the number of vibrations varies inversely as the length of the string, provided no other change be made in the string.

210. A String Vibrates in Parts in Addition to Vibrating as a Whole.—A string may be caused to vibrate as if it were a series of separately vibrating strings fastened end to end. If the string be touched lightly at the middle, and struck at the same time at a point $\frac{1}{4}$ of the length of

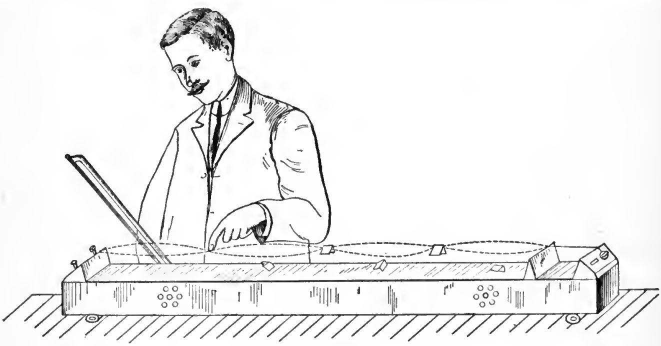


FIG. 95.

the string from the end, it will vibrate in two sections of equal length. If the string be touched at a point one-third of its length from the end, and struck at a point one-sixth of its length from either end, it will vibrate in three sections of equal length.

Cause it to vibrate in four sections, by touching it at one-fourth its length from the end. Little V-shaped pieces of paper hung across the wire at the ends of the sections will not be thrown off, but pieces of paper placed at the middle of these sections will fly off (Fig. 95). This indicates that the vibrations are strong at the middle of

the four sections, but nearly at rest at the ends of the sections. In other words, the string is vibrating like four sections of equal length.

A string vibrating in 2, 3, or 4 sections vibrates like several strings, each $\frac{1}{2}$, $\frac{1}{3}$, or $\frac{1}{4}$ as long as the entire string. Each section, therefore, now produces 2, 3, or 4 times as many vibrations as the string vibrating as a whole produced. This change can be recognized by the increase in height of the pitch, as the string is made to vibrate in more numerous sections. A string, which, when vibrating as a whole, produces C on the bass staff, will produce middle C on the piano, when it vibrates in 2 parts; G on the soprano staff, when it vibrates in 3 parts; and upper C on the soprano staff, when it vibrates in 4 parts.

A string can be made to vibrate in parts at the same time that it is vibrating as a whole. Stretch a string so that it produces middle C when vibrating as a whole. Strike it strongly at a point one-sixth of its length from the end. You will hear not only middle C, but also high G above the soprano staff, showing that the string is at the same time vibrating as a whole and also in three sections.

211. Instruments Producing the Same Fundamental Tone are Distinguished by Their Overtones.—All musical instruments vibrate in parts, while at the same time vibrating as a whole. The higher tones due to the vibration of the instrument in parts are called *overtones.* The tone produced by the vibration of the instrument as a whole is called the *fundamental tone.* Many instruments produce at the same time nine or more overtones of different pitch. Most of these overtones produce pleasing combinations with the fundamental tone and increase the musical quality of the sound produced by the instrument.

While all musical instruments produce overtones as well as fundamentals, all do not produce the same overtones, or at least do not produce the same overtones with the same degree of loudness. Hence, the musical effects resulting from the combination of fundamentals and overtones are different in different instruments. This makes it possible to distinguish different kinds of instruments, even when they are producing the same fundamental tone.

212. Many Vibrations may be Transmitted Through the Air at the Same Time.—One might suppose that it would be impossible for several sets of vibrations to pass through the air at the same time without becoming hopelessly confused. However, that this is not true is shown by every-day experience. The vibrations sent out by the various instruments of a large orchestra all travel at the same time through the air. Yet they can all be heard, and a skilful conductor can at once pick out the instrument which makes the slightest mistake. In the same manner, a skilful director can distinguish the individual voices of a chorus.

213. The Velocity of Sound.—The velocity of sound in air at the ordinary temperature (72° F.) is about 1130 feet per second. This velocity increases and decreases at the rate of 1 foot per second for every increase or decrease of 1 degree in the temperature of the air. The velocity in water is $4\frac{1}{3}$ times as great; in pine wood, 10 times; and in iron, more than 15 times as great as in air. Hence the sound of a blow on the railroad track a quarter of a mile away may be heard coming through the rail more than a second before it can be heard through the air.

214. The Structure of the Ear.—For the purpose of description, the passage between the opening into the ear and the auditory nerves may be divided into three parts.

The first part of this passage is a tube called the *external auditory canal.* It is about one and a quarter inches in length. For a distance of about half an inch from the opening into the ear, the canal wall is cartilaginous and, therefore, movable; for the rest of its extent, about three-fourths of an inch, it consists of bone covered by a thin skin.

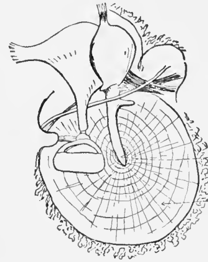
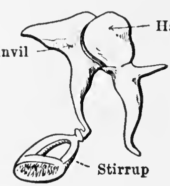


FIG. 96.

The second part of this passage is called the *tympanum* or middle ear. It is an air-holding cavity of irregular shape hollowed out in the solid bone of the head. It is about one-third of an inch long, one-fourth of an inch high, and one-sixth of an inch wide.

Between the external and middle ear is stretched the membrane known as the *ear drum* (Fig. 96). It is nearly circular and has a diameter of nearly three-eighths of an inch. Since the ear drum is stretched over the cavity of the middle ear, this cavity is called the *tympanum* (Latin for drum).

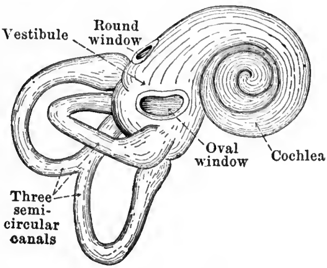


Bones of the Ear

FIG. 97.

The third part is called the *labyrinth* or internal ear. It is a liquid-holding cavity of irregular shape hollowed out of the solid bone (Fig. 98). The lower half, occupying the portion nearer the inner part of the head, has the form of the interior cavity of a snail-shell, and, on this account, is called the *cochlea,* from the Latin word for shell (Figs. 98, 99); it consists of two and one-half spiral turns. The upper and more exterior half consists of three tubes, called *semicir-*

cular canals, each tube bent in the form of a semicircle and placed at right angles to the others. The open ends of the semicircular tubes and of the snail-like tube all open into the central portion of the labyrinth.

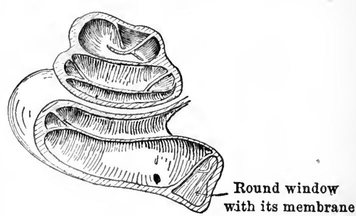


Bony labyrinth

FIG. 98.

The two small entrances from the middle ear to the inner ear are called the *oval window* and the *round window*, and are also each covered by a thin sheet of membrane. Since both entrances to the internal ear pierce the walls of the central portion, this part is called the *vestibule* of the inner ear. The inner ear itself is called the labyrinth, because of the bewildering number of passages it contains.

In the middle ear, between the ear drum and the membrane covering the oval window, is a series of three irregular bones (Figs. 96, 97). To the first bone attached to the ear drum has been given the fanciful name of *the hammer*, and, since its thickened rounded head rests against the second bone, this bone is called the *anvil*. The tip of the second bone is attached to the end of a third bone which looks exactly like a minute *stirrup*. The flat end of the stirrup is fastened to the membrane stretched over the oval window opening into the vestibule of the inner ear. Any motion of the ear drum



Section of left cochlea

FIG. 99.

is at once transmitted by these bones to the oval membrane.

Within the snail-like part of the inner ear, the cochlea, is stretched the *basilar membrane* (Fig. 100). This membrane consists of 16,000 to 24,000 minute fibres, which are stretched transversely across the length of the passage in the cochlea. These fibres are looked upon as a sheet of parallel strings, similar to the series of wires in a piano. The longer fibres are found nearer the smaller end of the spiral tube, where, at first thought, they would scarcely be expected. These fibres are weighted with the various *cells of Corti*, to which are connected the *auditory nerves*.

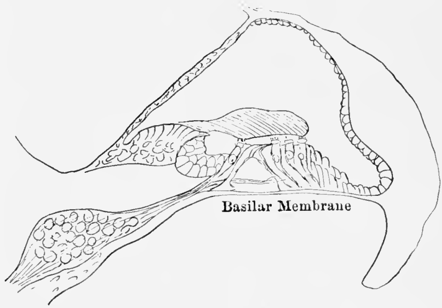


FIG. 100.

A large part of the structure of the ear has purposely not been described. A fuller knowledge may be secured from some large work on physiology (American Text Book of Physiology, published by W. B. Sanders, Philadelphia.)

215. The Communication of Sound to the Nerves of the Ear.—When the molecules of air set in motion by the vibration of some other body strike against the drum of the ear, the ear drum is made to vibrate at the same rate as the molecules of air. The vibrations of the ear drum are communicated by the series of bones in the middle ear to the membrane closing the oval window which leads to the inner ear. The membrane transmits the vibra-

tions to the liquid filling the labyrinth. Among other places, the vibrations reach the liquid filling the snail-like cavity, or cochlea. Here the molecules of the vibrating liquid are in contact with the fibres of the basilar membrane. Those fibres of the membrane which vibrate naturally at the same rate at which the molecules of the liquid in the cochlea are now vibrating, take up the vibrations of the liquid. These vibrations are communicated then to the *cells of Corti*, which weight the fibres, and these finally produce a sensation in the *auditory nerves* connected with the cells. The perception of this sensation by the brain is called *hearing*.

Not only is the vibratory motion communicated from body to body, but the same rate of vibration is taken up in succession by the air, ear drum, bones in the middle ear, membrane covering the oval window, fluid in the cochlea, and, as far as we know, also by one or several of the fibres of the basilar membrane.

The taking up of the vibrations by the basilar membrane is another case of sympathetic vibration. It will be remembered that, when a tone is sung loudly in front of the piano, that wire of the piano which possesses the same pitch begins to vibrate also.

CHAPTER VI

RADIANT ENERGY—HEAT AND LIGHT

216. Some Vibrations may Produce both the Sensation of Heat and of Light.—The sensations of heat and light are entirely different in character and they are felt by entirely different nerves. The nerves of temperature terminate in the skin and extend to almost every part of the surface of the body (§ 130). The nerves of sight, however, terminate at only one spot, the eye. It therefore might reasonably be supposed that the sensations of heat and light are due to very different phenomena, just as the sensations of sound and smell are unquestionably due to entirely different causes. The following experiment, however, suggests that the sensations of heat and light may be due to exactly the same phenomena.

Place a piece of iron in a very hot flame. At first while it rises in temperature, it gives out merely more and more heat, and this heat may be felt by the nerves of temperature. However, after a certain temperature has been reached, the iron not only gives out heat, but also emits light, not a bright light but at least a light that can be seen—a dull red. This suggests that if the increase in temperature of the iron is due to an increase in the rate and intensity of vibration of the molecules of the iron (§ 120), that light may be due to more rapid vibrations and that slower vibrations are not able to produce the sensation of light. If this idea is correct, the general

statement can be made, that a great variety of vibrations can produce a sensation in the nerves of temperature, but only the more rapid vibrations can produce any sensation in the nerves of sight. If red is the first color seen when a body is raised in temperature, then all the other colors should also be produced by the more rapid vibrations. This has been shown to be true, but not by means of the simple experiment here described.

If the temperature of the iron be increased above that necessary to produce the dull red color, the iron will give out a brighter red, then a reddish-orange, later a yellow, and finally a white color. In following paragraphs it will be shown that many other colors are given out, but that these are so mingled together that until we learn how to separate them, we are not able to recognize their presence (§ 231). For the present it will be sufficient to recognize the fact that vibrations of many degrees of rapidity may produce the sensation of heat, but that only the more rapid vibrations can produce the sensation of light.

217. The Transmission of Heat by Contact of Molecule with Molecule.—Heat may pass from one part of a body to another, by the communication of heat from molecule to molecule. When the molecules do not change their relative positions, as in the case of solids, this method of transference of heat is called *conduction* (§ 121). When the molecules change their relative positions, as in the case of liquids and gases, it is called *convection* (§§ 125, 127). In both cases heated molecules come in contact with others not yet heated, and communicate to them a part of their own heat.

When water is boiled in a kettle, the hot molecules in the flame communicate a part of their heat to the molecules of iron forming the exterior of the kettle. This heat is

communicated from molecule to molecule until it reaches the interior of the kettle. Here it is transmitted to the molecules of water in contact with the kettle, and, as these move away, other molecules of water may take their places and also become heated.

218. The Air does not Transmit the Heat or Light from the Sun to the Earth.—Heat may also be transmitted from molecule to molecule without direct contact, and without any transmission by means of an intermediate set of molecules. During a hot cloudless summer day the temperature at the surface of the earth rises frequently to 100° F. However, as one ascends to regions above the earth, a steady lowering of the temperature is observable. Near the surface of the earth the temperature decreases at the average rate of 1° F. for every increase in elevation of about 300 feet. At an elevation of several miles above the earth the rate of decrease of temperature is considerably less. This is shown by the fact that Glaisher found a total decrease in temperature of only 61° F. when he ascended in a balloon to a height of 5 miles. Nevertheless we have every reason to believe that at a distance of 100 miles above the surface of the earth, the temperature must be nearly 460° below zero, Fahrenheit. Since the temperature of the air at the surface of the earth is higher than the temperature of the air nearer the sun, it is evident that the heat and light of the sun reach the earth without being conducted to the earth by the air.

219. No Air is Present in the Greater Part of the Space Between the Sun and the Earth.—The density of the air diminishes as the elevation above the surface of the earth increases. At an elevation of $1\frac{3}{5}$ miles the air is not $\frac{3}{4}$ as dense as at sea level, at $3\frac{1}{2}$ miles it is less than half as dense, at 6 miles it is less than $\frac{1}{4}$ as dense (§ 17). It is

evident that 100 miles above the surface of the earth the air must be exceedingly rare.

How do we know that air of any degree of density is present 100 miles above the earth? Tiny particles of rock flying through space frequently come in contact with the atmosphere of the earth. Since the speed with which the earth moves is about 18.5 miles per second, and since the particles of rock are also moving rapidly, the total speed with which the particles of rock and the earth approach each other may amount to as much as 45 miles per second. When the particles of rock strike the molecules of the air, the heat produced, as a result of the concussions, is so great that both air and rock become white hot and are then visible in the form of shooting stars. When larger masses of rock strike the air, they not only give out a much more brilliant light, but occasionally portions of the rock reach the surface of the earth, and are then called meteorites. When two observers in neighboring towns notice the same meteor and record the angle at which it appears above the horizon, it is possible to determine the elevation of the meteor, as soon as the distance between the two towns has been measured. Observations of a similar kind indicate that the tiny particles of rock which become shooting stars occasionally become visible at elevations between 70 and 100 miles above the surface of the earth. Therefore at 100 miles above the surface of the earth some air is still present.

Since no shooting stars ever appear at a greater elevation, it is evident that at still higher elevations the quantity of air continues to decrease until finally air is practically absent. By far the greater part of the space between the earth and the sun cannot contain air. But if air is present for only a short distance between the

sun and the earth, then, along most, if not all, of the distance between the sun and the earth, the heat and light of the sun must be transmitted by means of some other medium than air.

220. Heat and Light may be Transmitted Through a Vacuum.—The possibility of the transmission of heat and light through a vacuum may be demonstrated experimentally.

Enclose the blackened bulb of a thermometer within a glass globe. By means of a mercury-pump withdraw the air which is in the globe, and melt shut the opening through which the air was pumped out (Fig. 101). By

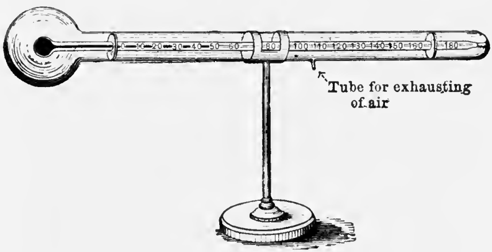


FIG. 101.

means of this type of pump it is possible to get an almost perfect vacuum. Less than a millionth of the air is left behind.

If a red-hot poker be held near the globe, the mercury in the thermometer instantly rises. Since the interior of the globe is practically a vacuum, air cannot have served as a medium for the transmission of heat, at least in the space between the walls of the globe and the bulb of the thermometer. The part of the thermometer enclosed in the globe can be seen as readily through the vacuum as before the removal of the air. Therefore, light can also pass through a vacuum.

221. In Order to Explain the Transmission of Heat and Light Through Space in which no Material Substance Is Known to Be Present, the Existence of Ether Is Assumed. —It is impossible to conceive of the transmission of heat from the sun to the earth without the existence of some intervening medium. For this reason scientists have proposed the theory that all space which is apparently empty is in reality filled with something which they call the *ether,* and they have suggested that in all cases in which heat is not transferred by some known medium, in other words, by contact of molecule with molecule, the heat is transferred in some manner by the ether. Knowing what phenomena of heat and light it was necessary to explain by means of the ether, scientists then proceeded to determine what must be the properties of the ether, in order that it might show these phenomena.

They soon came to the conclusion that the ether must be colorless, inconceivably light in weight, more elastic than any substance actually known to exist, and so all-pervading that it not only occupies all space ordinarily considered as a vacuum, but even fills the space between the atoms of ordinary matter. It is therefore believed to be vastly more continuous than anything actually seen on earth ; for the molecules of even the densest substances are known to be not in actual contact with each other, since every decrease in temperature at once brings them closer together. This ether can be set in vibration by the vibrations of the atoms imbedded within the ether. It can transmit these vibrations to more distant parts of the ether, and it can communicate this vibratory motion to other atoms at a distance from those atoms which originally set the ether in motion.

This theory at first rested chiefly upon imagination,

and was merely an attempt to explain many phenomena otherwise inexplainable. However, within recent years this theory has been found capable of explaining so many phenomena in heat, light, and electricity, that the existence of ether may be considered as proved. Some scientists have even attempted to determine approximately its density and elasticity (Principles of Physics, Daniell. Macmillan & Co., New York).

A liquid known as ether is sold in drug stores. The ether which transmits light has no connection with this liquid. The ether known in theory is entirely invisible, and, if it were not for the phenomena of heat, light, and electricity, its existence would never have been suspected.

222. Radiation.—When a pebble falls into a pool of water, it starts a series of waves. The waves spread out in every direction and set in motion every light object floating upon the water.

According to the ether theory vibrating atoms start waves in the ether surrounding each atom. These waves are transmitted by the ether in every direction and strike other atoms imbedded in other parts of the ether. In consequence these more distant atoms also begin to vibrate.

The ether theory may be used to explain the transmission of heat and light from the sun to the earth without the use of air. The atoms forming the sun vibrate at an exceedingly rapid rate. This produces a vibratory motion in that part of the ether surrounding each atom and gives rise to waves traversing the ether. These waves pass through the enormous spaces devoid of air but filled with ether. On reaching the atmosphere surrounding the earth, the wave motion of the ether gives rise to vibratory motion in the atoms forming the air. At the surface of the earth they cause the atoms present in the rock-forming

compounds to vibrate, since these also are imbedded in the ether. In fact, the atoms of all substances at the surface of the earth are more or less affected, since ether pervades all space, even the space between the atoms of the densest substances.

The vibratory motion of the atoms gives rise to the phenomena known as heat. Some atoms take up the vibratory motion more readily than others, and therefore become hotter. On this account rocks become hotter than air. When the rate and intensity of the vibrations communicated to the atoms are sufficient, the vibratory motion of the atoms gives rise to both heat and light. In proportion as the ether sets the atoms imbedded within it into more violent vibration, the intensity of its own motion decreases. Hence the heating effects of the sun do not penetrate very far beyond the surface of objects struck by its rays.

The transmission of vibrations capable of producing the sensation of heat, or of both heat and light, is called *radiation.*

223. Ether may Serve to Transmit Heat and Light even when Air is Present.—If, on a cold winter day before the room has become warm, we stand before a large fire in an open fireplace, the heat striking the body may be so great that it even scorches us; but if a large screen be placed between us and the fire, we will at once feel cold. Yet we know by experience that air does not become cold instantly when the source of heat is removed. Is the air between us and the fire actually warm?

If we place a delicate thermometer behind a piece of wood which will serve as a screen for the thermometer, and then hold it thus protected between us and the fire, we will learn that the temperature of the air is still low.

However, the instant the thermometer is removed from behind the piece of wood and allowed to face toward the fire, the temperature rises considerably. Those parts of our bodies which face the fire also feel much more heat than can be accounted for by the actual temperature of the intervening air, as indicated by the thermometer. The vibrations of the heated atoms in the fire are transmitted by means of the ether which is between the atoms forming the air. As soon as the waves set up in the ether increase sufficiently the rate of vibration of the atoms of mercury, the thermometer indicates a rise in temperature. Waves of a still higher rate of vibration may produce both the sensation of heat and of light.

224. Refraction of Light Passing Obliquely from Water to Air.—The waves set up in the ether spread in every direction from the centre of disturbance. Each wave may be looked upon as a spherical shell enlarging with enormous rapidity. When waves strike obstructions only the unobstructed parts of waves may continue their progress. Hence light passes through rifts in clouds in long sheets or *beams.* Through smaller apertures the wave continues its course in the form of *rays.* Since every part of a wave travels in a radiate manner directly away from the centre of disturbance, that part of the wave which continues its path through a small aperture is *straight*, at least as long as the substance through which it passes has the same density. Hence rays of light are straight.

However, when a ray travels through substances having different degrees of density, the path followed by the ray changes at each point where a new substance is entered. The bending of a ray of light on passing from one substance into another can be shown easily by the following experiment.

Place a coin in the centre of a pan set on a low table. The sides of the pan should be nearly perpendicular, and almost 4 inches high. Take a position at such a distance that, when you glance across the edge of the pan, only the farther margin of the coin is visible (Fig. 102). The light from the coin now passes in a straight line through the air past the edge of the pan to the eye. Now let

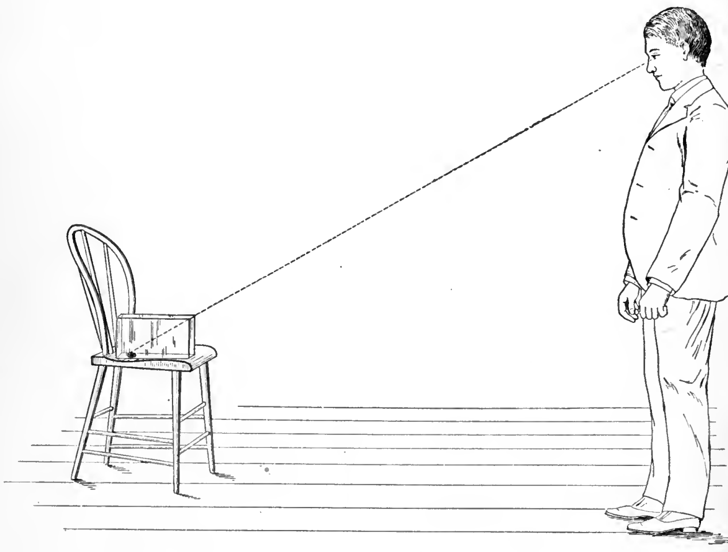


FIG. 102.

some one fill the pan with water up to the brim, and then lower the head until the light from the farther margin of the coin is again seen just above the edge of the pan (Fig. 103). The path of the light is now partly in water and partly in air. That part of the path which extends from the farther margin of the coin to the edge of the pan passes in a straight line through the water. The re-

mainder of the path, from the edge of the pan to the eye, passes in a straight direction through the air. But the eye is no longer in its former position. The path of light has been evidently bent downward at the surface of the water near the margin of the pan. This bending of the light while entering another substance at an oblique angle is called *refraction.*

If the coin be watched while the basin is filling with water, it will be noticed that the coin comes into view and seems to move upward and toward the centre of the

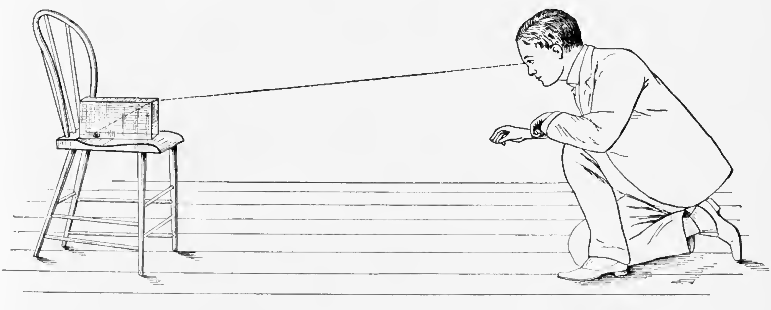


FIG. 103.

pan as the water increases in depth. This effect is produced by the bending of the rays of light as they pass from the surface of the water out into the air. By further study it may be determined which rays are bent, what was their former course, and why the coin seems to move. The only purpose of the preceding experiment, however, is to bring out the fact that *light is bent downward on passing obliquely from water into air.*

225. Refraction of Light which Passes Obliquely from Air into Glass, and from Glass into Air.—Secure from a dealer in physical apparatus a rectangular piece of plate-glass,

5 inches long and 3 inches wide, whose long, narrow sides have been ground so as to be flat and parallel, and then polished so as to be almost perfectly transparent. Lay the glass on the table, several inches from the margin. Stick a pin into the table, several inches behind the plate of glass, and then lowering the head to the level of the table, look at the pin through the entire width of the glass. Move the head toward one side until the lower part of the pin as seen through the glass

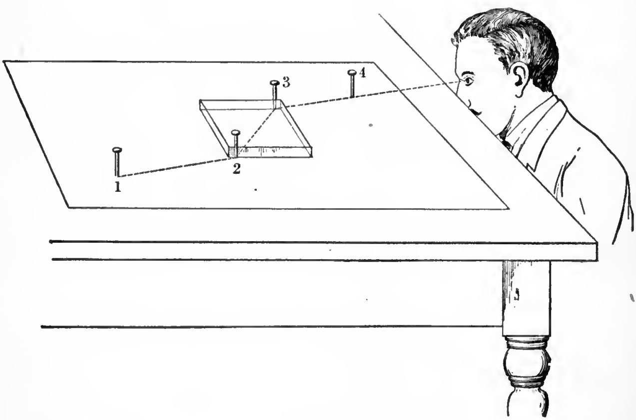


FIG. 104.

is very far out of line with the upper part of the pin as seen through the air, above the glass. Then, without moving either the plate or the eye, stick a second pin into the table, in contact with the more distant of the polished faces of the glass, so as partly to hide the lower part of the first pin looked at through the glass (Fig. 104). This will mark the point where the light from the first pin enters the glass. Stick a third pin into the table, in contact with the nearer polished face, so as to hide the

lower part of the second pin. This will indicate where the light from the first pin would leave the glass and re-enter the air if not obstructed by the second pin. Finally, stick a fourth pin in the table, several inches in front of the plate, so as to hide the third pin, which is of course in plain view. This will indicate in what direction the light from the first pin would pass on leaving the glass if not obstructed by the other pins.

If the position of the head has not been changed, all four pins appear to be in a straight line while the observer is looking through the entire width of the glass. However, if the head is lifted and the pins are connected

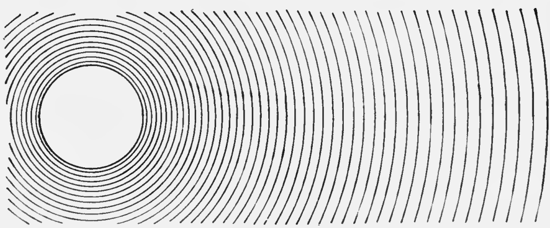


FIG. 105.

in their order by straight lines, it will be found that the light from the first pin bends both on entering the glass and on re-entering the air, but the bending in the two cases is in opposite directions.

226. A Small Portion of a Spherical Wave is Practically Flat.—The cause of the bending of the rays of light in passing from one substance into another may be explained in the following manner:

The vibrations of atoms at the source of heat and light produce spherical waves which spread through the ether in all directions from the centre of disturbance outward. In their spherical form they resemble the waves of sound

(§ 203). At a considerable distance from the original cause of disturbance the curvature of any small portion of the front of a wave is very small (Fig. 105). Therefore, any small part of the wave front may be treated, in a theoretical discussion, as if it were flat.

It may be interesting in this connection to notice that many people still believe that the surface of the earth is flat, because the small portions of its surface which they can see at any one time often appear flat.

227. Refraction of Waves Due to Variation in Amount of Speed of Waves while they are Passing through Different Substances.—If a thick flat piece of glass is held in front of a wave advancing through the ether in the air, a portion of the wave will enter the glass. If the glass be held obliquely, that end of the glass which is nearer to the wave front will be entered first.

It has been found that light does not travel as fast through glass as it does through air. Consequently the velocity of that part of the wave which enters the glass first will be retarded (Fig. 106), while the remainder of the wave continues to travel with its original velocity, until it also enters the glass. This permits the lagging end of the wave to catch up partly with that end which enters the glass first. In consequence the wave front swings around so that it is more nearly parallel to the surface of the glass, after it has entered the glass, than it was before.

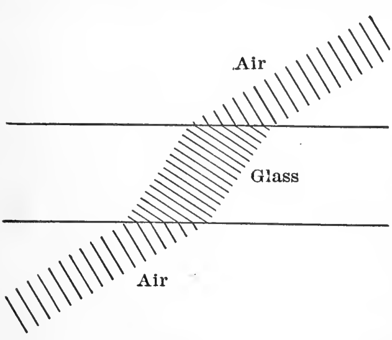


FIG. 106

As soon as the entire wave front has entered the glass there is no further change in direction, since all parts of the wave, while in the glass, travel with the same velocity. Since each part of a wave always moves in the direction in which the wave front faces, it is evident that the wave, on entering the glass, will take up a path which is different in direction from its path in air.

The mathematical statement of this change of direction is that *light bends toward the perpendicular in passing from air into glass.* The perpendicular is supposed to be erected at the point where the light enters the glass and is supposed to be perpendicular to the surface of contact between the air and the glass.

Any substance which retards the speed of the wave more than glass will cause a greater change in the direction of the wave front, and, therefore, in the path taken by this portion of the wave.

When a wave passes obliquely from glass into air, the part of the wave which enters the air first moves faster than the part of the wave still travelling through glass. The result is that by the time the entire wave has entered the air its front makes a larger angle with the surface of the glass than it did while it was completely within the glass.

The mathematical statement of this change of direction is that *light bends from the perpendicular on passing from glass into air.*

The direction in which light travels is similarly changed on passing from any substance by which it is more retarded, into another substance by which it is less retarded, the amount of change in direction depending upon differences in the amount of retardation offered by the two substances concerned.

It is necessary to remember that when light is said to pass through air, water, or glass, the waves are in reality passing through the same substance,—ether. In some manner, the atoms imbedded within the ether retard the speed of the waves passing through it, each kind of substance retarding the speed of these waves to a different degree.

228. The Refraction of Light Passing Through a Prism.—When light passes from air into glass, it bends toward the perpendicular. When light passes from glass into air, it bends from the perpendicular. If a piece of glass is so cut that the surface by means of which the light leaves the glass has a different direction from that at which the light enters (§ 225), the light after leaving the glass will have a different direction from that at which it entered. By placing the second surface at the proper angle, it is possible to make this surface bend the light still farther from its original course than it was bent by the first surface.

Secure a large glass prism with flat ends, so that, when the prism is set up on one of these ends, the prismatic faces will be vertical. A triangular piece of plate glass with polished edges or a bisulphide of carbon prism will do just as well. Stick a pin into the table several inches behind the prism and look at it through the sides of the prism. Slowly turn the prism until the apparent position of the pin, as seen through the sides of the prism, is as far removed as possible from the actual position. Then, without moving the head or the prism, place in contact with the more distant face of the prism a second pin, locating the point at which the light coming from the pin to the eye enters the glass (Fig. 107). In contact with the nearer face place a third pin marking the point at

which the light leaves the glass. Between the eye and the prism place a fourth pin, hiding the third pin, to determine in what direction the light travels after leaving the third pin. While looking through the glass the four pins appear to be standing in a straight line.

Remove the prism and connect the pins, in order, with straight lines. It will be found that the path of the light has twice changed its course, once on entering the glass, and again on re-entering the air. Both changes

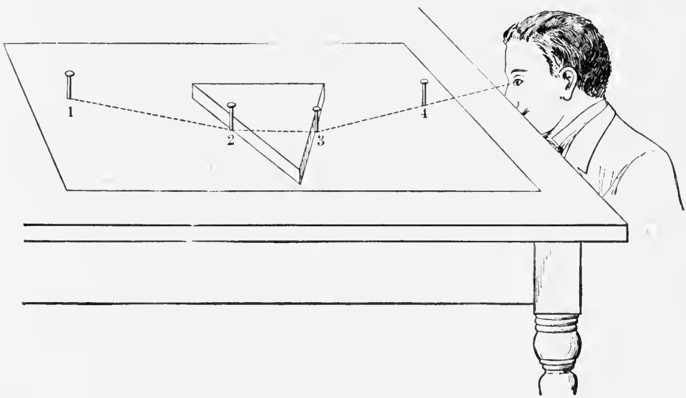


Fig. 107.

result in turning the light toward the same side of the original path. Mark the positions of all pins, and of the two faces of the prism through which the light passed on its way from the pin to the eye.

229. The Refraction of Yellow Light.—Send a ray of yellow light through the same prism in such a manner that it may follow as nearly as possible the path of light recorded in the preceding experiment, and locate the directions followed by the yellow light after it has passed

through the prism. In order to do this with accuracy, the following apparatus will be found convenient.

A source of yellow light.—When the access of air to the lower part of a Bunsen burner is not cut off, it burns with a faint, bluish flame which is scarcely visible. However, if sodium carbonate be placed in the flame, it gives off an intense yellow light. The most convenient manner of getting sodium carbonate into the flame is to dip one end of a platinum wire in hydrochloric acid; then dip

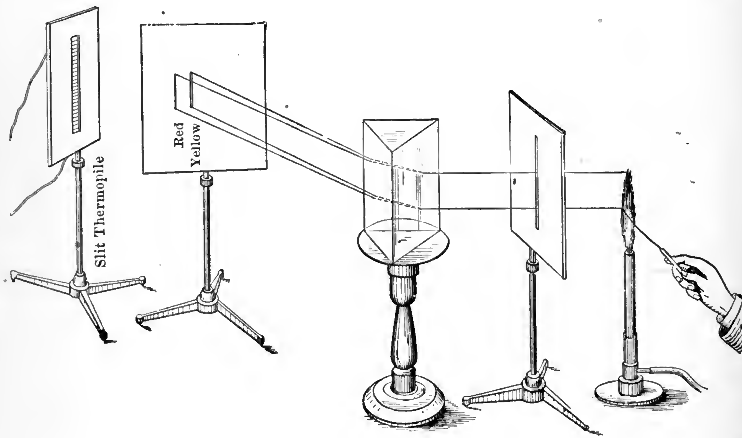


FIG. 108.

this end into powdered sodium carbonate, and hold it in the flame of the burner (Fig. 108). The wire is supplied with a glass handle (§ 36).

A screen with a narrow slit—to permit the passage of only a narrow beam of light. This screen can be easily made by boring a hole an inch or more in diameter through a thin board about 8 inches wide and 12 inches long and tacking two straight-edged strips of tin over this hole so as to form a vertical slit about half as wide as the thick-

ness of a pin. The hole should be bored in such a position that, when the board is set on end on a table and a Bunsen burner is placed by the side of it, the hole will be on a level with the flame of the burner. On each of the lower corners of the board nail a small strip of wood to serve as a support to keep the screen in a vertical position.

Set up a carbon bisulphide prism at a distance of about 6 inches from the slit of the screen, and place the Bunsen burner on the other side of the screen at a distance of about 10 inches from the slit. The prism, slit, and luminous part of the flame should have the same elevation above the table, so that when in position they lie in the same horizontal plane. On looking at the slit through the prism we find that the yellow light, resulting from the use of sodium carbonate, comes through the slit and is bent from its straight path by the prism in a manner similar to that discussed in connection with the preceding experiment.

230. The Refraction of Red Light.—Use lithium carbonate instead of sodium carbonate. The flame is colored strong red. The red light is also refracted by the prism, but it is refracted less than the yellow light. If both sodium carbonate and lithium carbonate are placed in the flame at the same time, the flame is colored with a mixture of yellow and red light. The prism, however, will separate this mixture into its elements, and the yellow light and the red light are seen through the prism as two distinct narrow vertical lines (Fig. 108).

If a prism can separate all compound colors in this manner, it is possible to use a slit and prism in order to determine what simple colors are present in any compound color.

231. White is a Compound Color.—The light of the sun is white. This fact may be recognized readily when sunlight falls upon a piece of paper on the floor.

Without shifting either the screen or the prism, remove the Bunsen burner and, by the use of one or more mirrors, reflect a little sunlight along the path formerly followed by the yellow and red lights in their course through the slit toward the prism; as a result, a broad band of light formed by a regular series of colors with red at one end and violet at the other is seen through the prism. The

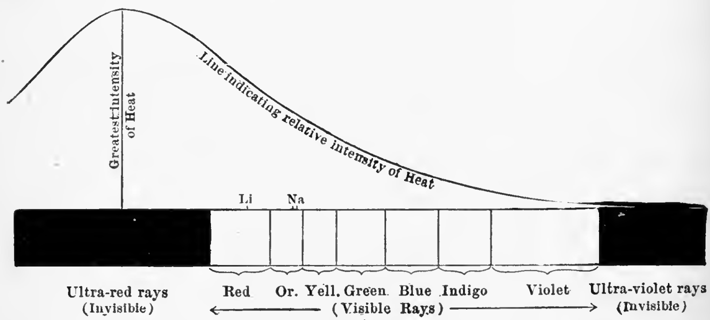


FIG. 109.

v. i. g. b. y. O. R.

order of occurrence of these colors is: red, orange, yellow, green, blue, indigo, and violet (Fig. 109).

If these colors be examined more closely, it will be found that each so called color in reality consists of many tints of color, so that there are many tints of red, many tints of green and many tints of the other colors. These tints grade into each other imperceptibly, so that it is impossible to find any natural line of separation between the red and orange, orange and yellow, yellow and green, or any other neighboring colors of this band. Such lines of separation are often drawn for the sake of

convenience in discussing the different tints produced, but their location is arbitrary.

It is, therefore, evident that the white light of the sun consists of a great many colors, or at least of a great many tints. The number of tints is so great that, even when they have been separated by means of a prism, they form a practically continuous band of color. While it is convenient to speak of this band as consisting of seven colors, it should be remembered that, in reality, it consists of thousands of tints. The prism has separated these colors in such a manner that they can be studied separately.

White light is a compound color. It contains a greater number of simple colors than any other compound color known. In fact, it contains all of the simple colors. For that reason, the colors present in white light are used as the standard with which the simple colors found in all other compound colors are compared. Among the colors present in white light may be located the particular tint of yellow produced by sodium carbonate, and the particular tint of red produced by lithium carbonate. Since the simple colors present in white light can be recognized only when separated by means of a prism, they are called the *prismatic* colors, and the band of colors formed is called the *spectrum* of white light. When the sun is the source of the white light, the spectrum is commonly spoken of as the *solar spectrum*.

232. The Growth of the Spectrum During Increase of Temperature on Heating a Platinum Ball.—Place a Bunsen burner in such a position that when a platinum ball, held in the flame, becomes hot enough to emit light, the light will pass, through the slit and the prism, toward the eye, as in the preceding experiments. The first

light which the ball gives out on being heated has a dull red color. In tint it corresponds to the dull red at the extreme limit of one end of the solar spectrum. Looked at through the prism this dull red color is seen as a vertical line. As the heating of the ball continues, its color not only becomes more intensely red but it also changes in tint. If during this change of color the light coming from the ball is examined through the prism, it is noticed that new tints of red are added to those already formed so that the original vertical line of dull red appears to broaden out into a *band* of red. Since the growth of the band takes place in one direction only, the dull red color first seen always forms one end of the band, while the new tints of red are added in succession to the other end.

The addition of new tints of red is only one of the changes to be noticed on heating the ball. If the tints of red successively added to those already present be examined closely, it will be seen that they become brighter, or more intense. The examination of the ball through the prism, therefore, shows that as the ball grows hotter, new tints of red are added and that those already present become more intense.

The brighter red color of the platinum ball as seen without the prism is evidently due to the combined action of all of the changes just described, but without the use of the prism it is not likely that the exact nature of the changes of color of the ball would ever have been detected. The prism makes it possible to determine to what the changes in the color of the ball are due.

As the heating of the ball is continued, the band seen through the prism continues to grow—by adding various tints of orange-red, then of reddish-orange, orange-

yellow, yellow, yellowish-green, green, greenish-blue, blue, bluish-violet and violet, always to the same side of the band, until all of the colors seen in the solar spectrum are present. In the meantime the intensity of the tints first present increases as before.

The changes in the compound colors produced by the addition of new tints as the heating progresses are far less striking. First there is a mixture of the different red tints; then a mixture of red and orange, producing a bright red effect; then a mixture of red, orange, and yellow, which gives a somewhat yellowish tinge to the red. As the other colors of the spectrum are added to those already present, the compound color varies from reddish-yellow to white. Since the red tints of the spectrum are the first to appear when a platinum ball is heated, these are the first colors to become very intense. Therefore, red strongly predominates in the compound colors produced during the earlier part of the heating of the ball.

233. Each Prismatic Color in the Spectrum is Due to a Different Rate of Vibration.—The original cause of sound is the vibration of some body. This vibratory motion is taken up by the air and is transmitted in the form of waves. Increase in the rate of vibration of the sounding body results in an increase in the number of waves sent out per second. This is recognized by the ear as an increase in pitch. Increase in the amplitude of vibration of the sounding body causes stronger condensations in the air. In consequence the waves move forward, not more swiftly, but with greater energy. Hence, the sound heard is louder. Anything which causes a greater quantity of air to be set in motion, for instance, a sounding-board, also increases the total energy with which the waves move forward, and adds to the loudness of sound.

In the same manner, the original cause of light is the vibration of atoms, or of the combinations of atoms called molecules. This vibratory motion is taken up by the ether and is transmitted in the form of waves. Increase in the rate of vibration of the atoms results in an increase in the number of waves sent forward by the ether in each second. If these vibrations are sufficiently rapid, the waves produce the sensation of light and color. Any further increase in the rate of vibration of the atoms results in a change of color, the tint produced being nearer the violet end of the solar spectrum. Increase in the amplitude of vibration of the atoms causes the waves set up in the ether to move with greater energy. This is recognized as an increase in the intensity of the color produced.

Most sounding bodies produce simultaneously many vibrations differing in intensity and rate of vibration. This has already been discussed in connection with fundamental tones and overtones. The waves set up simultaneously in the air produce a combined effect, recognized as the characteristic quality of the sound.

In a like manner, the various atoms of the same heated body may differ so much in their rate and intensity of vibrations that only the combined effect can be recognized without the use of a prism. This combined effect may also result in the perception of color, but it is a compound color.

Something similar to this is unquestionably true also in the case of heat, since heat and light are due to the same phenomena. The phenomena of heat, however, are usually investigated in an entirely different manner from the phenomena of light, and we have no terms which are strictly comparable with the terms *pitch* and *loudness* in

sound, or with *tint* and *intensity* as applied to the spectrum colors. The temperature of a body depends, of course, on the rate of vibration of its atoms or of the groups of atoms known as molecules, but the temperature of a body as registered by a thermometer depends also upon the amplitude of vibration of the molecules and upon the number of the molecules which are vibrating; in other words, upon the size of the body. The quantity of heat in a body depends also upon the rate and amplitude of vibration of its molecules and upon the number of molecules present in the body. However, a great quantity of heat usually implies a large body, while a high temperature may be shown by a small body.

234. Vibrations whose Rates are too Slow to Produce Light are Deflected Beyond the Red End of the Spectrum. —All waves pass through the ether at the same speed. The waves due to the less rapidly vibrating atoms which produce a red color, pass through the ether with the same rapidity as the waves due to vibrations sufficiently rapid to produce a violet color. Since each vibration of an atom gives rise to one wave, a greater number of waves must be produced in one second by a rapidly vibrating atom than by one vibrating more slowly. If the rate of vibration of an atom is regular, it will send off waves at equal intervals of time. These waves must, therefore, be an equal distance apart. If the distance from one wave to the next is called a wave length, the length of the waves produced by a rapidly vibrating atom must be shorter than the length of the waves produced by a more slowly vibrating atom. Hence the waves producing the colors nearer the violet end of the spectrum must be shorter than those producing the colors nearer the red end. An examination of the solar spectrum shows that

the larger waves producing colors near the red end of the spectrum are deflected less than the shorter waves.

Vibrations of atoms too slow to give rise to the sensation of light also produce waves. These waves must be longer even than those of the dull red at one end of the spectrum. Although invisible, they also must pass through the prism, but should be deflected less and hence the search for them should be conducted beyond the red end of the spectrum. How may these waves be detected if they are not capable of producing the sensation of light? Some instrument other than the eye must be used. A very delicate thermometer might be serviceable. A thermopile, however, is better.

235. A Thermopile is Used to Detect Extremely Small Variations in Temperature.—A thermopile is an electrical instrument which is capable of detecting much smaller changes in temperature than even the most delicate thermometer. Thermopiles have been constructed which are capable of detecting a variation in temperature of less than one-millionth of a degree. It is not necessary to describe the instrument here, since a full description may be found in any larger book on physics. A slit thermopile is most convenient in detecting the presence of waves which have been deflected by a prism. The method of its use is sufficiently well explained in "A School Course in Heat," by Larder, Sampson Low, Marston and Co. London.

236. Relative Intensity of Heat Produced by the Different Waves Giving Rise to the Solar Spectrum.—The use of the thermopile may be illustrated by investigating the relative intensity of heat produced by the waves giving rise to the solar spectrum. Cause a small quantity of light from the sun to pass through a narrow slit and a prism, and then allow it to strike the surface of a large piece of

white paper. The prism will deflect the different tints to different positions on the paper, and the result will be the appearance on its surface of a broad band of colors, the solar spectrum.

By moving the thermopile in front of the paper so as to permit the various tints to fall in succession upon the thermopile, the relative intensity of heat given out by the different waves producing light can be compared. Instead of a glass prism, a salt prism is used, since salt absorbs far less of the wave motion than glass. § 255.

By studies of this kind it has been discovered that the lowest intensity of heat is produced by the short waves at the violet end of the spectrum, and that the intensity of heat increases on approaching the red end of the spectrum (Fig. 109). A similar fact is true of the spectrum of the platinum ball.

The greater intensity of heat produced by the longer waves due to the lower rates of vibration in the case of the *platinum* ball is possibly due, not only to the greater intensity of these vibrations, but also to the fact that, even when the platinum ball has become white hot, the number of molecules vibrating at a lower rate is probably still much greater than the number of molecules vibrating at a higher rate. The same supposition may also be made to account for the similar phenomena just described in the case of the spectrum of the sun.

X **237. Relative Intensity of Heat Produced by the Invisible Waves Deflected Beyond the Red and the Violet Ends of the Spectrum.**—It has been shown that, when a thermopile is moved from the violet to the red end of the spectrum, an increase of temperature is indicated. If the motion of the thermopile is continued in the same direction, beyond the red end of the spectrum, it is found that the

thermopile indicates an increase in intensity of heat even after the dull red tint at the very extreme of the visible part of the spectrum has been passed (Fig. 109). This increase continues until a certain distance beyond the end of the visible spectrum has been reached, after which the thermopile indicates a decrease in the intensity of heat. The fact that the thermopile is affected at all indicates the presence of waves beyond the red end of the spectrum and that these waves may be detected by the thermopile even when they cannot be seen by the eye.

It is an interesting fact that the greatest intensity of heat is produced, not by the waves causing the red colors of the spectrum, but by invisible waves having a considerably greater length, whose position is some distance beyond the red end of the spectrum.

The possibility of invisible waves producing great intensity of heat is shown by the flame of the Bunsen burner, which is intensely hot, but which (when well regulated) scarcely gives out any light.

If the thermopile is now moved in the opposite direction, from the red to the violet end of the spectrum, it is found that invisible waves exist also in the region beyond the violet end of the spectrum (Fig. 109). These waves are shorter than any visible in the spectrum, but they are unable to produce the sensation of light. Moreover they cause even a less intensity of heat than the violet rays. The farther the waves are beyond the violet end of the spectrum, the less is the intensity of heat.

238. Ultra-Red and Ultra-Violet Parts of the Spectrum. —The word spectrum was originally used to designate the band of colors produced by light passing through a prism. Since the prism separates all waves passing through it, both visible and invisible, and distributes them

in the order of their length, it is possible to speak of the entire series of waves after they leave the prism, as the spectrum. That part of this spectrum which includes the waves capable of producing the sensation of light is then called the *visible spectrum.* The invisible waves which are deflected to points beyond the red end of the spectrum form the *ultra-red spectrum,* and the invisible waves which are deflected beyond the violet end of the spectrum form the *ultra-violet spectrum.*

239. Nerves of Sight Not Sensitive to All Rates of Vibration.—The vibrations which produce the dull red tint at the red end of the visible spectrum have a rate of 392 trillions per second; the vibrations at the extreme limit of the violet end of the visible spectrum have a rate of 752 trillions per second. Some eyes are sensitive to lower and some to higher rates of vibrations than others. This merely corroborates the view, that the inability of the eye to see all vibrations transmitted through the ether is due not to any special difference between visible and invisible vibrations, aside from their rate of vibration, but is caused by a lack of sufficient sensitiveness in the nerves of the eye.

As already stated there are vibrations whose rate is less than that giving rise to red at the extreme end of the visible end of the spectrum. In addition to the rays which are capable of giving rise to the sensation of heat, but not of light, are found waves whose frequency is very much less. Some of these are known as the Hertz waves, and produce the results utilized in wireless telegraphy. On the other hand, the frequency of the vibrations present in X-rays very much exceeds the frequency shown by the violet rays at the other end of the spectrum.

240. Natural and Artificial Sources of Light.—In order that light may be seen, there must be a source of light, a

source capable of producing those waves to which the eye is sensitive. Very few bodies act as sources of light or are self-luminous. Most bodies merely reflect or transmit light. The sun is the most important source of light. The moon merely reflects a part of the sunlight which falls upon it. That part of the moon's surface upon which the light of the sun does not fall remains dark. The stars are also sources of light, as may be seen easily on a night when the moon is not shining. The most important artificial sources of light are those due to rapid combustion: such as, the burning of wood, coal, coal-oil, acetylene gas, and other materials. The light given out by the flame is due to particles of carbon which once were parts of the wood, or coal-oil, and which for a moment are heated enough to give out light. Any particles not burned up before they leave the flame remain unconsumed and pass off as smoke. In the incandescent electric light the carbon filament is heated white hot, but is not burnt.

The flash of lightning is due to intense, rapid vibrations of the atoms forming the air, set in motion by electricity. The light given out by the fire-fly is also due to very rapid vibrations of atoms. The heat produced by the fire-fly is small. This may be due to the small intensity of the vibrations belonging to the red and ultra-red parts of the spectrum, or to the small number of vibrating atoms.

241. Different Sources of Light Give Out Different Colors.—Different sources of light may produce different waves, or may produce waves which are alike in length but differ in energy. It has already been shown that sodium carbonate, placed in the flame of a Bunsen burner, gives out yellow light, and that lithium carbonate gives out red light. In reality the compounds are broken up, and

the elements, sodium and lithium, give out the yellow and red light respect. Other substances give out different colors. The light from a coal-oil lamp consists of all the waves present in sunlight, but the yellow and red colors are relatively more intense and the blue, bluish-violet, and violet colors less intense, than corresponding colors in the light from the sun. Hence objects illuminated by lamplight often appear to have colors differing from the colors of the same objects seen in daylight.

242. Most Objects are Visible Only While they Reflect or Transmit Light.—Most objects do not give out light of their own. They are visible only by means of the light which they receive from various sources of light, and then either reflect or transmit.

If a room were closed so that not even a single ray of light could enter it, and if no artificial source of light (a lamp or electric light) were introduced, not a single object in the room could be seen. During nights when the moon is not shining, and when the clouds are thick enough to absorb almost all of the light from the stars, we are able to appreciate more fully the fact, that most objects can be seen only because they reflect or transmit light.

Even a tiny ray of light illuminates many parts of a darkened room. The light is reflected from object to object, and scattered in so many directions by any uneven surface, that a little light is finally reflected from most objects in the room. In a similar manner, objects not in direct sunlight receive the light of the sun after reflection from many other bodies.

243. Difference of Color of Opaque Objects Due to their Inability to Reflect All or a Part of Certain Prismatic Colors.—All objects which are not transparent are visible only when they reflect light. The light which they re-

flect depends upon the light which falls upon them. It is a familiar fact that, when red light alone falls upon a piece of white paper, the paper appears red. When yellow light alone falls upon it, the paper appears yellow. But this is not true of all objects. All objects cannot reflect the same color. Therefore the color of an opaque object depends, not only upon the colors which fall upon it but also upon the colors which it can reflect.

This may be shown by taking some source of light which contains all of the prismatic colors, and investigating which of these colors different bodies can reflect.

By means of a mirror reflect a beam of sunlight through a narrow slit into a darkened room. Let the light pass through a prism, as before, and then let it fall upon a sheet of white paper. The paper is white, because it reflects all the colors present in sunlight. It is able, therefore, to reflect each one of these colors singly, after all the colors have been separated by the prism. This is the reason for the use of *white* paper in this experiment. Change the position of the paper, until the prismatic colors spread over as large an area as possible.

Place a piece of red flannel in front of the different colors of the spectrum. When red light falls upon it, it has its usual strong red appearance. When other colors fall upon it, it appears dark or black. Red is the only color which it reflects well. Therefore, it appears red even if all the prismatic colors present in sunlight fall upon it. But when the light which falls upon the flannel does not contain any red light, when for instance it contains only green light, the flannel is not able to reflect the green light, the only color which it receives. Since it fails to reflect any color, it appears black.

Cover a smooth piece of wood with soot by means of a

lamp- or gas-flame. Hold it in various parts of the spectrum. It reflects none of the prismatic colors. Black, therefore, is the absence of all color. Absolute blackness is due either to a complete failure to reflect light, or to a complete absence of light to be reflected. Most objects called black are not absolutely black, but reflect a sufficient quantity of some one prismatic color to make it more appropriate to speak of the color as bluish-black, greenish-black, or some other shade of black.

244. Compound Colors Due to Selective Reflection.—If now a great variety of substances be tested by holding them in different parts of the spectrum, it will be found that some substances reflect only one color well, and, therefore, possess a color which approaches one of the prismatic colors. Other substances reflect one prismatic color well and two or three other prismatic colors in a very moderate degree. The prismatic color which is well reflected usually gives its name to the resulting compound color. The other prismatic colors reflected determine the characteristic tint. The general color effect produced by the mixture is usually very different from the effect of any of the prismatic colors: for example, greenish-blue, orange-red.

Many substances reflect a number of prismatic colors in such quantities that the compound color produced has no resemblance to any of the prismatic colors. By persons not students they are often looked upon as of equal rank with prismatic colors. Brown, gray, drab, lilac are compound colors.

Among the objects to be examined it is well to have quite a number which are distinctly and strongly colored. Light-colored objects appear light, because they reflect a considerable amount of almost all of the other prismatic

colors, in addition to the prismatic colors which strongly predominate; for example, light-red ribbons.

245. Reflection of Heat.—Since most substances are not able to reflect *all* of the prismatic colors which form the *visible* part of the spectrum, it is probable that most substances also cannot reflect *all* of the waves which form the *invisible* part of the spectrum. Moreover, since both visible and invisible waves can produce the sensation of heat, this is practically equivalent to saying that most substances vary considerably in their ability to reflect heat. This subject is difficult to investigate, since most of the waves producing heat are invisible, but it is well known that some bodies reflect a much greater portion of the total quantity of heat falling upon them than others. Polished metals are among the best reflectors of heat. Lampblack is the poorest reflector of heat known.

246. Heat May be Reflected by a Cold Surface.—If we stand at one side of an open fireplace, out of reach of the direct heat, in a room that has not yet been heated for a sufficient length of time to become warm, and, if some one standing in front of the fire suddenly places a large bright sheet of tin in such a position that the light of the fire is reflected upon us, we not only instantly perceive the light, but we are at the same moment aware of a considerable quantity of heat. However, if we touch the tin quickly we find that it is still cold. The heat that has come to us is not the heat of the tin, but the heat of the fire reflected by the tin.

247. Colorless Transparent Substances Transmit All of the Prismatic Colors.—Many transparent substances show no indication of color. If one of these substances be held anywhere along the path of light which is reflected by a mirror or porte-lumiere into a darkened room and toward

a prism, it will be found that the transparent substance has absorbed so little of the various prismatic colors present in sunlight, that the spectrum on the screen remains practically unchanged. In fact, these substances are called colorless, because they transmit all colors unchanged and, therefore, produce no perceptible effect upon the colors of objects seen through them.

248. Differences of Color Transmitted by Transparent Objects Due to Their Inability to Transmit All or a Part of Certain Prismatic Colors.—Any object seen through a piece of red glass looks either red or black. The reason for this may be readily seen if the red glass is held so that the sunlight passes through the glass before it enters the prism. The spectrum on the screen is changed in appearance. Most of the colors have evidently been stopped by the red glass. Only the red colors have been allowed to pass through freely. The other colors which are transmitted, are transmitted only in small quantities. If a kind of glass could be found which would transmit absolutely nothing but red, only objects which give out, reflect, or transmit red light, could be seen through it. Since only red light would be transmitted by this kind of glass, all objects seen through the glass would appear red. Objects not giving out red light, but giving out only other colors, would be invisible and the spaces occupied by them would appear black.

This does not mean that only those objects which appear red to the unassisted eye could be seen through a piece of red glass. It should be remembered that most of the colors occurring in nature are compound colors. Most of these colors contain (in addition to other and often more evident colors) more or less of the prismatic colors called red. For instance, the color of an ob-

ject which appears blue to the naked eye may also contain a small quantity of red, so that when the object is viewed through red glass, it will be visible, and will apparently have a dull red color. How prevalent these red prismatic colors are in almost all of the combinations of colors reflected by objects in nature, may be better appreciated by looking at these objects through a piece of red glass. It will at once become evident that almost all objects reflect or transmit some red color, although the quantity of red color thus reflected or transmitted, may be so small that it cannot be noticed until the red glass is used, or until the prism separates the red from the other colors.

Hold other kinds of colored glass in the path of the sunlight, before it enters the prism. It will be found that green glass transmits chiefly green; blue glass, chiefly blue; other kinds of glass, other colors. In each of these cases, the predominant prismatic color transmitted gives name to the color of the glass.

When several prismatic colors are transmitted in considerable quantities, their combined effect is often so dissimilar to the effect of any single prismatic color, that special names have been coined to designate the combination of color thus produced.

Throw a spectrum on the wall and look at it through differently colored pieces of glass.

249. Color of Glass Usually Recognized by Light Reflected from Other Bodies.—It is not necessary to hold the glass between the eye and some source of light in order to determine its color. No matter in what position the eye is held, a sufficient variety of colors is usually reflected by various objects beyond the glass to enable the glass to transmit to the eye about the same combination

of colors which it transmits when it is exposed to sunlight. Therefore, if the glass be held between the eye and the floor, the eye and a building, or the eye and a plot of grass, a range of prismatic colors will be sent by the various objects through the glass to the eye which will be sufficient to give the glass its usual color.

250. Color of Light Transmitted Through a Succession of Differently Colored Substances.—If a kind of glass could be found which transmitted nothing but red, and another kind which transmitted nothing but green, no light could be transmitted through both glasses if they were held together. The red glass would transmit only the red light, and this red light would be absorbed soon after it entered the green glass, so that nothing could pass through both.

As a matter of fact, however, most green glass transmits not only green light, but also a little red light, so that objects seen through both red and green glass appear dull red. In the same manner most blue glass transmits not only blue light, but also a little red light, so that objects seen through both red and blue glass appear dull red. Blue glass transmits a little green in addition to blue, and green glass transmits a little blue in addition to green, so that objects seen through both have a peculiar bluish-green color affected a little by the red which is transmitted by both kinds of glass. But a combination of red, green, and blue glasses will absorb so much of all the different colors, that very little light of any kind, except a faint tinge of red, can pass through all of them. The result is that no objects can be seen through a combination of all of the three kinds of glass here mentioned, unless they give out a very considerable quantity of red light. Ordinarily objects do not do this, but the light of the sun or of an electric light contains enough of

the strong red colors to be seen through all of these glasses used together.

251.—Effect of Thickness upon the Color of Transparent Substances.—The colors which enter glass, but which are not transmitted, are absorbed. They are not absorbed at once, but are absorbed more and more as they penetrate deeper into the glass. The thickness of the glass will, therefore, determine how much of these colors will be absorbed. If a thin layer of colored glass examined by means of a prism shows that it absorbs very much more of some colors than of others, it is certain that thicker layers may absorb all of the more readily absorbed colors, while they will still transmit considerable quantities of those less readily absorbed. The compound colors produced by light passing through thicker layers of this kind of glass will not contain some of the prismatic colors which are transmitted through thinner layers. The colors of certain kinds of glass, therefore, depend, to a certain extent, upon the thickness of the glass.

The influence of thickness upon the color of transparent substances may be seen by placing an increasing number of pieces of blue glass between the eye and the sun, or by examining different thicknesses of litmus solution by transmitted light.

252. Almost All Opaque Substances are Transparent in Very Thin Sections.—Since no substance is known which reflects all of the light which falls upon it, some light must enter every substance, even those substances called opaque. A substance is called opaque when the light which enters it is not able to penetrate far into the substance before it is stopped (absorbed). Since the light which enters the opaque substance must penetrate some distance before it is absorbed, light may pass through any

opaque substance if a thin enough layer of the substance can be obtained. Hence every substance is transparent to some degree.

In practice, it has been found that it is very easy to secure sections of wood which are thin enough to be transparent. There is such little difficulty in securing transparent sections of even the blackest rocks that one of the courses in geology (petrography) consists in a study of the mineralogical composition of rocks by means of a microscopical investigation of thin transparent sections.

Even gold is transparent, when it is secured in thin films. Gold reflects a yellow color, but if thin films of gold are placed between pieces of glass in front of the light of a magic lantern, they will transmit green light. Very thin films of silver transmit blue light.

Therefore, when we say that a substance is opaque we mean that an ordinary thickness of the substance is opaque. Sufficiently thin layers of this substance are almost certain to be transparent.

253. The Colors of Opaque Objects Partly Due to Internal Reflection.—When light is thrown upon glass, a part is reflected by the surface of the glass, and a part, after it has passed through the glass, is reflected by the air at the rear of the glass. The result is that, if a lighted candle be placed before a thick piece of plate-glass, two images of the candle are formed. The front image is due to the reflection of light by the front surface of the glass; the rear image is due to the reflection of light by the air in contact with the rear of the glass.

If the glass is colorless, the light is not altered in color as it passes through the glass and back again, after reflection, to the side of the glass from which it came. But if the glass is colored, for instance if the glass is red, the

light which traverses the thickness of the glass and then returns is red, for red glass absorbs all the other colors.

In the same manner, the light entering many so-called opaque objects is reflected by different materials within a very short distance of the surface, and so returns to the original surface, containing only those rays which thin sections of the opaque objects are not able to absorb.

It is probable that the colors of all opaque objects are due to partial absorption of the colors which fall upon them. While these bodies are called opaque, the light in reality penetrates for a short distance and is reflected again toward the surface, but only the light not absorbed during the transition again reaches the surface, and gives the characteristic color of the object. Any color reflected from the actual surface of an object is probably reflected practically unchanged.

254. Color of Pigments.—Copper sulphate and potassium bichromate both form transparent crystals. Copper sulphate transmits blue chiefly; it absorbs most of the red, orange, and yellow, but transmits a little green (Fig. 110, A). Potassium bichromate transmits orange-red chiefly, the color noticed on examining the crystals; it absorbs most of the blue and violet, but transmits a little green (Fig. 110, B). The solutions absorb and transmit the same colors as the crystals. The result is that when a copper sulphate solution is held in front of a potassium bichromate solution the only color which is transmitted to any considerable extent by both solutions is green, and hence the light seen through both solutions appears green, and a mixture of these solutions also appears green (Fig. 110, C, D).

If a very small quantity of finely powdered potassium bichromate is added to a larger quantity of finely pow-

dered copper sulphate, and the mixture is then thoroughly stirred, a slight change of color is noticeable. If the proportion of potassium bichromate is gradually increased, the mixture finally becomes a distinct light green, or apple-green. Any light which strikes the mixture penetrates it for some depth before it is reflected back to the surface, and, since during its passage through the mixt-

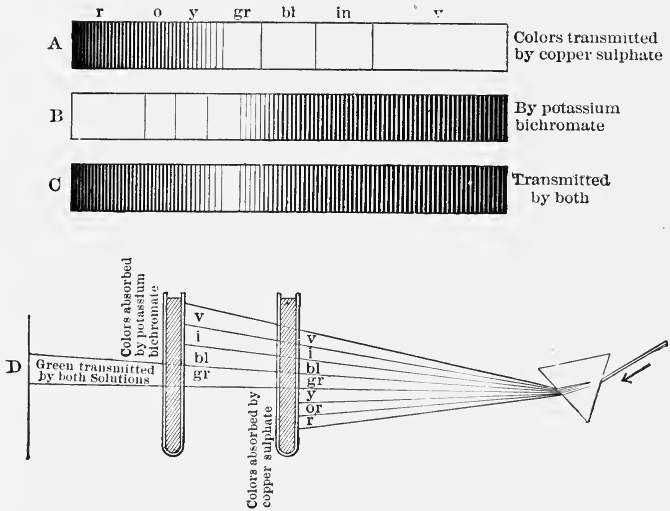


FIG. 110.

ure all the colors except green are absorbed, the mixture appears green. Mix in the same manner chrome yellow and ultramarine blue (§§ 244 and 253).

255. The Relative Transmission of Visible and of Ultra-Red Waves Varies in Different Substances.—Since most substances are not able to transmit equally well all of the prismatic colors which form the visible part of the spectrum, it is probable that most substances cannot

transmit all of the waves formed by the invisible parts of the spectrum. This fact is shown to a certain extent by the following observations.

Rock salt appears to transmit the invisible ultra-red waves about as well as the visible waves of the spectrum. Hence prisms used to investigate the ultra-red part of the spectrum are usually made of rock salt. A solution of iodine in carbon bisulphide transmits none of the visible waves, but transmits a very considerable quantity of the invisible, ultra-red waves. Alum and ice transmit almost none of the invisible ultra-red waves, but transmit most of the visible waves of the spectrum. Since most of the heat given out by the light in a stereopticon comes usually from the invisible ultra-red waves, a solution of alum in water is often used to shield lenses and slides when images of microscopic objects are thrown upon a screen by means of a magic lantern or stereopticon.

Calcite, glass, and quartz transmit very little of the heat due to those invisible, ultra-red waves whose rate is low, but they transmit more of the more rapid ultra-red waves which lie nearer the visible spectrum, and they transmit most of the visible waves.

256. Good Reflectors of Visible and Invisible Waves are Poor Absorbers of Heat.—Those visible and invisible waves which fall upon a substance and which are neither reflected nor transmitted, seem to disappear entirely. They are said to be absorbed. What becomes of these waves? They increase the heat of the substance through which they pass (§ 257).

Those substances, therefore, which reflect the least light (and which probably also reflect the smallest quantity of the invisible waves) ought to show the greatest gain

in heat. This may be verified by an interesting experiment. Place upon the snow, in direct sunlight, three pieces of cloth, alike in every particular except in color. Suppose the colors chosen are white, red, and black. The snow will melt most rapidly around the black cloth, and least readily around the white cloth. The black color is evidently due to the absorption of most of the light of the sun, and white is due to the least absorption, since it evidently reflects all the colors to a considerable extent. Therefore, the black cloth becomes warm more quickly than the white cloth. What colors should be worn during summer? During winter?

Opaque bodies, if they are sufficiently thick, absorb all the light which enters them, with the exception, of course, of that part of the light which suffers interior reflection very near the surface of the body (§ 251). Lamp-black seems to absorb all waves (ultra-red and visible), and to reflect none. Most metals absorb about 13 or 14 per cent. of both the ultra-red and of the visible waves. They must, therefore, be excellent reflectors of both kinds of waves. For that reason certain metals were formerly used extensively for mirrors. So-called glass mirrors are panes of glass with a metallic coating (chiefly mercury) upon the back. This coating does most of the reflecting. The image reflected by the front of the glass is rarely noticed.

257. Good Transmitters of Visible and Invisible Waves are Poor Absorbers of Heat.—It has already been shown that substances vary considerably in their ability to transmit all the waves which form the visible and the invisible parts of the spectrum. Those substances which transmit most of the waves, especially of those invisible ultra-red waves which give evidence of the greatest intensity

of heat, will necessarily absorb but little heat and will therefore remain comparatively cold even in direct sunlight. Salt is one of the best transmitters and therefore is a poor absorber of heat. Glass transmits much less, and therefore absorbs much more of the heat. Alum, however, transmits but little heat and absorbs so much that it is used to protect other bodies from heat (§ 255). Most of the rock-forming minerals absorb more heat than they transmit. Air, on the contrary, absorbs but little heat. This fact may be recognized easily on a hot summer's day by placing the hand, which is already in contact with the air, on dry ground which has been exposed to direct sunlight. The contrast between the temperature of the ground and the temperature of the air is great.

The atoms forming the surface of the body may be set in vibration by the waves set up in the ether so readily that the face exposed to direct sunlight may feel burning hot, though, at the same time, the air in contact with the face may have a considerably lower temperature. The instant an umbrella is used as a screen, the air is felt to be cooler.

Water vapor is a much better absorber of heat than air, although both are very transparent to light. Therefore, moist air becomes hot much more quickly than dry air.

258. Explanation, by Means of the Ether, of the Connection between Good Absorption and Poor Transmission.—In attempting to explain the evident connection between good absorption and poor transmission of waves, or between poor absorption and good transmission, the following assumptions are made:

When atoms do not obstruct, to any considerable extent, the transmission of vibrations through the ether

within which the atoms are imbedded, the vibrations are transmitted through the ether with very little loss of energy; but the atoms are not set into very active vibration. Substances of this kind are good transmitters but poor absorbers of heat.

However, when atoms obstruct strongly the transmission of these waves, the energy of the waves in the ether is considerably diminished. If a sufficient number of these obstructing atoms be present, the energy of the waves passing through the ether within the interior of the body formed by these atoms becomes so small that the vibrations of the ether practically die out there. But, during this time, the obstructing atoms begin to vibrate violently, and are said to have absorbed the heat. Substances of this kind are good absorbers but poor transmitters of heat.

259. Good Absorbers are Good Radiators of Heat.—Investigators have shown by experiment that any body which absorbs heat readily gives it out again readily. Such a body is said to *radiate* the heat which it has absorbed. The sand of the desert of Sahara, which becomes heated quickly in daytime, cools down rapidly at night. The dark soil in our climate absorbs heat readily. When the sky is cloudless at night, the soil again gives up the heat readily; but if the sky be covered by clouds, this heat will be absorbed by the clouds, and then given back again to the air beneath, so that cloudy nights are not as cold as cloudless nights.

260. The Chemical Effect of Waves Belonging to Different Parts of the Spectrum.—If silver nitrate is placed upon some animal or vegetable substance and exposed to sunlight, the effect of the sunlight is to produce certain chemical reactions between the silver nitrate and

the other substances, and these reactions give rise to a change in color. In a similar manner, the light of the sun, falling upon the various silver compounds used in photography, causes a chemical reaction which, when it is followed by other chemical changes during the development of the plate, produces a black color.

It might be supposed from this that all objects which reflect much light will appear black after the plate exposed in the camera is developed. However, when the effects of various colors upon the photographic plate are studied, it is found that some colors produce much less effect upon silver compounds than other colors do. The chemical action is usually greatest when the plate is exposed to violet or bluish-violet colors, and it diminishes as colors nearer the red end of the spectrum are used. When the effects of the invisible waves beyond the violet end of the spectrum are investigated, it is discovered that these effects diminish in intensity, as the distance of these invisible waves from the violet end of the spectrum increases.

When the effect of light upon other substances which are not silver compounds is examined, very different results are obtained. Certain compounds of iron are most sensitive to waves which lie beyond the extreme red end of the spectrum. Each chemical compound which is likely to undergo chemical reactions when it is exposed to light, evidently absorbs waves of a certain rate best, so that the chemical action depends not only upon the frequency of the waves, but also upon the particular substance exposed to these waves.

261. Effect of Distance of an Object upon the Distance of the Image from the Lens.—Hold a double convex lens, or a lens both of whose faces are convex, a considerable

distance back from the window. Behind the lens place a piece of paper in such a position that the light reflected from some building may pass through the lens and strike the paper. Move the paper back and forth, until some position is found in which a fairly distinct image of the building is seen upon the paper.

A much better image may be secured in the following manner: Cut a hole in one end of a box, of such a shape and size that a lens may be inserted without permitting any light to pass between the margin of the lens and the

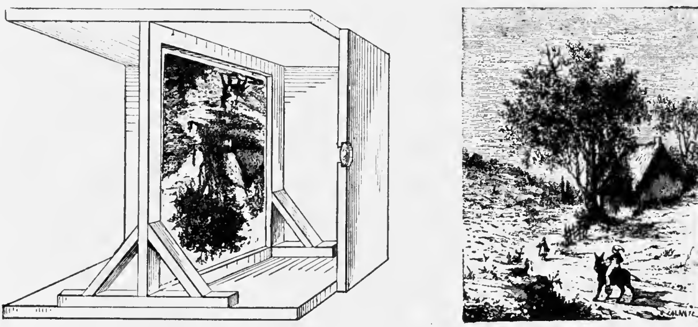


Fig. 111.

wood surrounding the hole (Fig. 111). Instead of paper use a piece of ground glass, fastened in a vertical frame, which can be moved backward and forward within the box. The end of the box opposite the lens should be left open, so that the image upon the ground glass may be readily seen. Secure an image of the same building and record the distance of the ground glass from the lens. Now carry the box to a point much nearer to the building, and move the screen again until another image is formed. The screen will be found to occupy a position farther from the lens. Replace the screen in the position it oc-

cupied when the first image was made. Now carry the box to a position much farther removed from the building than any position so far occupied. In order to secure an image, the screen must be moved nearer to the lens. The positions occupied by the screen at times when distinct images are formed are called *foci* (singular, focus). From the observations here recorded, it may be seen that there are a great many positions or foci at which images may be formed by the same lens, and that the distance of each focus from the lens depends upon the distance of the object from the lens. In photographic cameras the ground glass often occupies a fixed position and the lens is moved back and forth until the image falls upon the screen.

Instead of the building a gas flame or candle may be used as an object, and a piece of white paper will serve as a screen. The apparatus being placed upon a table, different positions may be given to the lens, and the screen may be moved back and forth until a distinct image is produced upon the paper.

262. Effect of Distance of an Object from the Lens upon the Size of the Image on the Screen.—If the size of the image be noted in the three cases described in the preceding paragraph, it will be found that the image is smaller when the object is farther from the lens, and larger when the object is nearer to the lens. In order to secure an image of an object very near to the lens, it may be necessary to move the screen back quite a distance from the lens. For this reason it is impossible to secure a good photograph if the camera be held very near to an object, unless the screen or photographic plate can be moved quite a distance from the lens. These facts can be most readily illustrated by using the gas flame or candle as an object and the paper as a screen as suggested in the last paragraph.

263. Effect of Convexity of Lens upon the Distance of the Image from the Lens.—If the lens in the opening of the box is replaced by one having a greater convexity, and the box is carried to each of the three positions occupied before, another series of images is secured. But, in each case, the image is found nearer to the lens than it was when the less convex lens was used. If the experiments be repeated with a lens of less convexity, the distance of the image from the lens will be found to be greater.

If a sufficient number of lenses of different convexity are at hand, it is possible to secure an image of any object, no matter at what distance, without moving the screen. If the object is very far away, it is necessary to use a lens of slight convexity. If the object is near at hand, a lens of greater convexity must be used.

264. Reason why the Image on the Screen is Inverted.—It is evident that in the preceding experiments any light coming from the top of the building and passing through the lens strikes the screen near its lower margin. Any light from the bottom of the building strikes near the top of the screen. Light from the left side of the building reaches the right side of the screen. In other words, the image produced upon the screen is inverted.

265. The Image Most Distinct when the Margin of the Lens is Not Used.—When the entire surface of the lens is used, it is found that the image is brighter, but not as distinct. If the margin of the lens is covered in some way, a considerable quantity of light is excluded. The image is, therefore, not so bright, but it is much more sharp or distinct. For this reason, cameras are provided with stops or diaphragms, which make it possible to use only the central part of the lens in bright weather. If objects are in motion, so that it is necessary to take an in-

stantaneous picture, it may be necessary to use the entire lens to secure a good photograph in a very short time. Moreover, if it be very dark, the entire lens must be used in order to secure sufficient light, if the exposure is to occupy only a short time.

266. Structure of the Eye.—The essential part of the eye consists of a lens, L, enclosed within the eyeball, near the front, and a screen, called the retina, R R, which lines the inner surface of the eyeball (Fig. 112). The image formed by the lens must fall upon the retina. If the image produced upon the retina is distinct, the object is seen distinctly. The position of the screen is fixed. The lens can be moved only a little forward or backward. There is only one lens, and it must serve to produce an image of any object, no matter at what distance from the eye. This can be accomplished only when the convexity of the lens can be changed at will, so that at times it can serve as a moderately convex lens and at other times as a strongly convex one. This changing is made possible by a series of muscles. It is possible to perceive the effort of the eye to change the convexity of the lens, when objects at very different distances are examined in succession. Near objects require a greater convexity of the lens and distant objects a smaller convexity. If the proper muscles are not able to give the

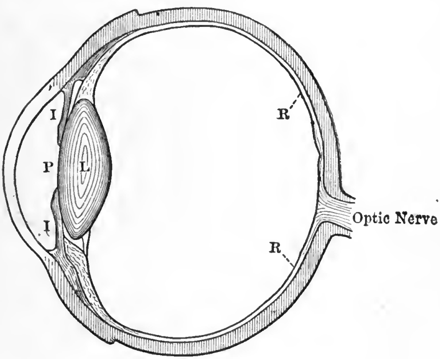


FIG. 112.

proper convexity to the lens in the eye, the image will not appear where it is needed. The lens will form an image in front or behind the retina. In this case the image will be blurred or indistinct. If the lens cannot be made sufficiently convex, convex spectacles must be worn. If the lens be too convex, concave spectacles must be worn to counteract this effect. Some persons need spectacles only when they are reading. This means that the eye can accommodate itself to all conditions, excepting when a very convex lens is necessary.

Immediately in front of the lens is suspended a circular curtain or diaphragm, called the *iris*, I I, which leaves a circular opening, *the pupil*, P, in front of the lens. This opening may be enlarged or diminished, so as to admit the use of more or less of the lens, according to the amount of light furnished by the object to be examined. In a dark room the opening through the iris (the pupil) is usually large. In very bright light, the opening is much reduced in size.

267. The Sensation of Sight.—The retina, upon which the image falls, is a transparent layer lining the interior of the eyeball back of the crystalline lens. The space between the retina and the lens and the space between the lens and the front of the eyeball is occupied by transparent liquids. Although the retina forms a layer only $\frac{1}{80}$ of an inch thick, it has a rather complicated structure, so that, for convenience of description, it is usually divided into ten layers (Fig. 113). These will be

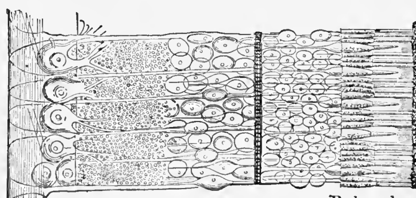


FIG. 113.

found well described in the larger books on physiology. For our purpose, it is sufficient to know that the nerves of sight enter as a bundle (optic nerve) at the rear of the eye (Fig. 112), directly opposite the lens, and, after passing through all the coats of the eye, spread out, so as to reach every portion of the retina.

That part of the thickness of the retina which is farthest removed from the interior of the eye contains a layer of bodies described as rods and cones (Fig. 113). The vibrations set up in these rods and cones are believed to be the cause of the sensation of sight. A number of facts indicates this, the most interesting among which is the following: The smallest star which can be seen in the sky is one whose apparent diameter is so small that lines drawn from the extremities of this diameter to the observer on earth would form an angle of only 60 seconds. The smallest distance which must exist between lines so that they may still be recognized as separate lines is such that lines connecting these lines with the eye give an angle which varies from 64 to 73 seconds. The sizes of the images formed upon the retina of the eye in these cases have been calculated, and it has been determined that the image of the star would have a diameter of .00017 of an inch, while the distance between the lines, in the image, would vary between .00018 and .00021 of an inch. Now the diameter of the rods and the cones varies between .00018 and .00022 of an inch. The exact character of the connection between the rods and cones and the nerves of sight has not been fully established.

268. Sensitiveness of the Eye to Different Colors of the Spectrum.—If the intensity of the different colors seen in the spectrum produced by sunlight be examined, it will be found that the greatest intensity of color is shown by

the tints nearest the yellow part of the spectrum. This is due to the fact that the nerves of our eyes are more sensitive to these tints than to any others. They are less and less sensitive to the other tints as these recede either toward the red or toward the violet end of the spectrum. Some experiments seem to show that the eyes are more sensitive to the blue colors than to the red colors at the extreme end of the red part of the spectrum.

CHAPTER VII

MAGNETISM AND ELECTRICITY

269. Natural Magnets.—It was observed by the ancients from the remotest antiquity that certain hard and very heavy black stones possess the remarkable property of attracting small pieces of iron. These stones were believed to possess a magical power, and are mentioned by many ancient writers. Although they excited much wonder, no practical use was made of them until about the twelfth century, when it was discovered that, if one of these stones is suspended so as to be free to turn in any horizontal direction, it always finally comes to rest in the same position—one end pointing North, the other South.

It is now known that these stones are pieces of magnetic iron ore, and, where this ore occurs in abundance, it is mined in order to secure the iron which is its chief constituent. Its chemical composition is Fe_3O_4. On account of its magnetic properties the ore is also called *magnetite.*

270. Artificial Magnets.—It is possible to give to a piece of steel the same properties as those possessed by magnetite. If the same end of a piece of magnetite is rubbed always in the same direction upon a knitting needle, the needle will attract iron filings and small tacks, and, if suspended by a thread, it will point approximately North and South (Fig. 114). By means of powerful electric currents it is possible to give these properties even to large

bars of steel. With these steel bars much heavier weights of iron or steel can be raised than can be lifted by any piece of magnetic iron ore of the same weight. The property of attracting iron or steel and of assuming a North and South direction is known as *magnetism*. Bars of steel possessing these properties are known as *magnets*. Pieces of magnetite are sometimes referred to as natural magnets.

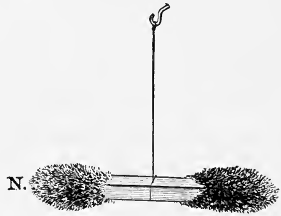


FIG. 114.

271. Soft Iron Readily Loses its Magnetism.—It is possible to give magnetic properties even to an ordinary piece of iron, but ordinary iron does not retain magnetism well. Magnetize a piece of iron wire about a foot long and one-eighth of an inch in diameter by rubbing it with a strong steel magnet. Dip the end in iron filings and notice the size of the cluster which adheres (Fig. 115, A). Then bend or twist the wire roughly and dip the same end into the filings. The magnetism is practically gone (Fig. 115, B). Some kinds of iron can be bent or cut so much more readily than others that they are called soft. The softest kinds of iron lose their magnetism at the slightest jar as soon as the magnetizing agency has been removed. Steel is the only material which retains magnetism well, and is, therefore, the only substance used for permanent magnets, although even steel loses its magnetism if roughly handled or heated.

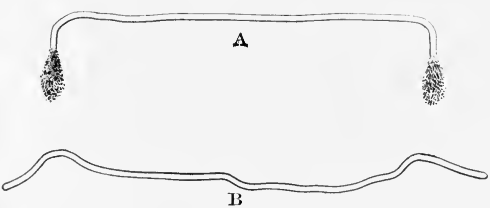


FIG. 115.

272. Only Iron and Steel Can be Strongly Magnetized.—Iron and steel are the only substances which can be magnetized strongly, and they are also the only substances which are strongly attracted by magnets. In the study of the ordinary properties of magnetism, all other substances may be ignored.

273. Magnetic Transparency.—All substances which are not readily attracted by magnets permit magnetism to act readily through them. They are therefore said to be magnetically transparent. It is impossible to pick up even a very small particle of iron by means of a piece of glass, but, if a small pane of glass is held against the lower end of a magnet, the force of the magnet acts through the glass, and it is possible to pick up tacks placed immediately beneath. The tacks are drawn up against the glass, but the instant the magnet is removed the tacks drop. Almost all other substances are magnetically transparent. Iron and steel are the only conspicuous exceptions. Substances are less transparent magnetically in proportion as they give evidence of greater magnetic properties.

274. Magnetic Poles.—When magnets are dipped in filings or tacks it is found that the filings or tacks adhere in tufts, and that the tufts are longest and most abundant along the edges near the ends (Fig. 116). Magnetism is therefore strongest near the ends of magnets and these ends are called *poles*. Every magnet has two poles. Both poles can pick up the same quantity of tacks, never-

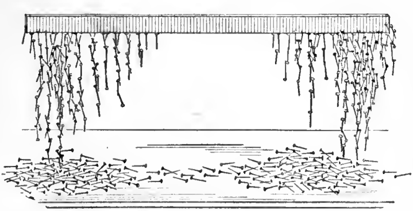


Fig. 116.

theless they must be quite different from one another, since one end always turns North and the other South.

That there is a difference between the poles of a magnet can be shown in another manner. Mark with chalk or paint those ends of two magnets which point North. Usually these ends are already marked with the letter N. Suspend one magnet horizontally by means of a thread and hold near its north-seeking end the north-seeking end of the other magnet. The two poles actually repel one another (Fig. 117). This result would certainly not be expected from anything previously stated. Now hold the south-seeking pole near the north-seeking pole of the magnet. The two poles seem to attract each other. Repeat the experiment in as many forms as you may be able to devise using other objects, such as the magnetic needle in a compass, and the same result will always be found. We may state these facts in the form of a rule as follows :—*Like poles repel each other ; unlike poles attract each other.*

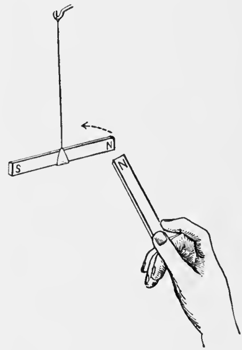
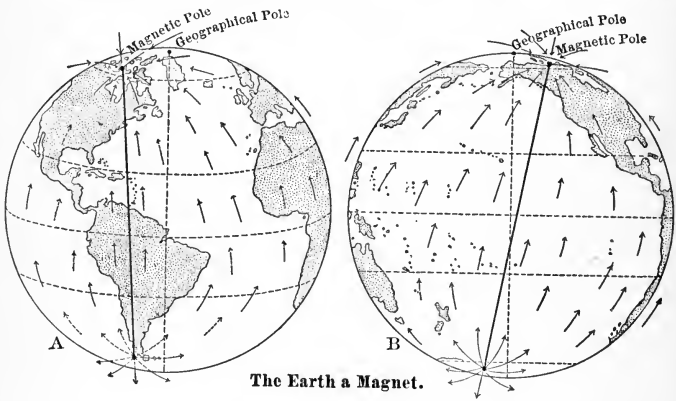


FIG. 117.

275. The Earth a Magnet.—This rule opens up another question. Why do all magnets, when suspended, point North and South? This is a very practical question, since the needle in every compass is merely a small magnet. A suspended magnet acts as though some south-seeking pole at some northern part of the earth were drawing the north-seeking pole of the magnet northward. Or, as if some north-seeking pole situated at some southern point on the earth's surface, were attracting the south-seeking pole of the magnet southward. Now, when we

examine the directions of the compass needles at all points of the earth's surface, we find that in the northern hemisphere their north-seeking ends all point in a general way to a point on the coast of North America, northwest of Hudson Bay (Fig. 118). And in a general way in the southern hemisphere the needles all point away from a locality in the Antarctic Ocean. This locality does not appear to be directly opposite the north magnetic pole (Fig. 118, A). Therefore, there is apparently a south-seeking pole near the North end of the earth which attracts



The Earth a Magnet.

FIG. 118.

the north-seeking pole of the compass needle and a north-seeking pole at the opposite end of the earth which attracts the south-seeking end of the needle. Apparently, the earth itself is a magnet with its poles at the North and South ends. Since only unlike poles attract each other, the magnetism of the poles of the earth and that of the attracted poles of the compass needle must be exactly opposite. This may be shown experimentally by placing a compass upon its side and moving it back and forth over a horizontal magnet.

276. The Compass.—The essential part of a compass is the needle. This consists of a small magnetized bar of steel supported on the sharp point of an upright pin by means of a cap of brass, glass, or agate attached to its centre. In this manner friction is reduced to a minimum and the needle can be moved by the slightest attraction. In the mariner's compass the apparatus is so arranged that the needle will remain horizontal notwithstanding the roll of the ship.

It was discovered by Columbus on his voyage to America, that the compass needle did not point to exactly the same part of the sky while sailing across the Western Atlantic as it did in Spain. At that time this could not be explained, but now we know that the magnetic pole in the Northern Hemisphere is not situated at the north pole as marked in our geographies, but northwest of Hudson Bay on the peninsula called Boothia Felix. The first pole is sometimes called the geographical pole, and the second the magnetic pole.

By looking at a geography you see that the needle must point west in Greenland, west of north in New England, and east of north in San Francisco. It so happens that in Ohio the needle points almost exactly north. The angle between the direction of the compass needle and the true North and South line is called the *declination* of the needle. The declination varies at different parts of the earth's surface, and in order that a navigator may know in what direction true North is located, he must have magnetic charts which give the declination of the compass needle at all points of the sea. Moreover, it is necessary to have the most recent charts, since the magnetic poles of the earth shift a short distance toward the East and West in the course of a number of years.

277. Variation in the Direction of a Compass Needle within the Field of a Magnet.—If a compass be placed at different points in the vicinity of a bar magnet, the direction of the needle will vary with the position of the compass. The space within which the bar magnet can influence the direction of the needle of a compass may be called the *field* of the magnet. In order to investigate the different directions assumed by the needle within this field, place the bar magnet on the centre of a large piece of paper. Hold the compass at different points in the field, and indicate in each case the direction of the needle by means of an arrow drawn directly beneath it. The point of this arrow should indicate the direction assumed by that end of the needle which points North when not in the vicinity of the bar magnet.

Continue the investigation until the entire field for a distance of at least six inches from the magnet is covered with arrows. It then becomes apparent that, although the direction of the needle varies considerably within the field of the magnet, this variation is in accordance with a definite plan. The arrows around one end of the magnet point away from the magnet, while those around the other end point toward it. The arrows at intermediate positions assume such directions that it is possible to connect them by means of curved lines starting out from one end of the magnet and finally entering the other. This appearance is strengthened by continuing the production of arrows until the paper is densely covered with them. If long lines are used to indicate the directions of the needle, the arrows frequently cross one another, but in proportion as the arrows are made shorter, the appearance of curved lines leaving the one pole of the magnet and entering the other is increased.

If a pane of glass is placed on a bar magnet, and iron-filings are sifted evenly over the surface, the soft iron-filings will temporarily become magnets. A gentle tapping of the glass will permit the filings to arrange themselves in directions corresponding to those which would be assumed under the same conditions by minute magnets (Fig. 119). In this case it becomes still more apparent that the directions assumed by numerous minute magnetic objects under the influence of a large magnet coincide with curves which may be drawn leaving one end of the magnet and entering at the other. These curves are called *lines of force.*

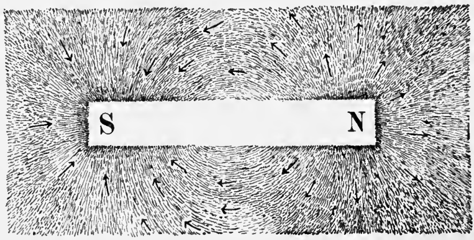


FIG. 119.

278. Magnetic Lines of Force.—It is not known precisely why magnetic needles arrange themselves in accordance with a definite plan within the field of a magnet. Within recent years, however, a number of ideas have been steadily gaining ground, and, at present, these ideas largely influence current views on this subject.

It may be noticed, in the first place, that the bar magnet influences the direction assumed by the compass needle placed within its field, although not in direct contact with the needle. If the original magnetic force resides in the bar magnet, this force must in some manner traverse the air in order to reach the needle, and the force must be conveyed by something, by some *medium.* Is this medium the air? This may be easily determined. If the

bar magnet and compass needle be placed under a bell-jar and the air exhausted, the action of the bar magnet upon the needle will remain exactly the same, proving that air is not the medium.

Since it is impossible to conceive of the action of one object upon another without either direct contact or an intermediate medium conveying the force indirectly, it is necessary to search for some medium. This medium which is present even in a space devoid of air is the ether, whose presence has already been found necessary to explain the various phenomena of heat and light. The theory is somewhat as follows:

In some manner a magnet is able to influence the ether in the air surrounding it. The space within which the ether is affected is called the *field* of the magnet. Within this field the ether is strained, and the direction of the strain is along curved lines. Small magnets are considerably affected by the strain produced in the ether by large magnets, and, if suspended or supported so as to swing freely, are forced to assume positions parallel to the direction of the strain. Another way of expressing the same idea is to say that the needles take positions at a tangent with the direction of the strain in the ether.

A compass needle may therefore be used to determine the direction of the strain of the ether at various points within the field of the magnet. As has already been shown by the preceding experiment, the direction of this strain is different in different parts of the field. The continual change of direction in the strain of the ether may be indicated by means of curved lines. These lines are drawn so as to leave one pole of the magnet, curve around through the field of the magnet, and enter at the other pole. Lines drawn in this manner may be called

lines of force. In reality they serve only to indicate the direction in which the ether is believed to be strained. There are no actual lines present in the ether. But drawings representing lines of force traversing the field around magnets enable the student quickly to grasp the chief properties of a magnetic field—the direction of the strain within the ether and the resultant direction assumed by any small magnet placed within this field.

279. Direction Assumed by North-seeking Pole of Magnetic Needle.—The strain in the ether present in the air surrounding the bar magnet determines not only the general direction assumed by the compass needle, but determines also the direction in which the north-seeking pole of the needle faces. In reality, the bar magnet does not affect the north-seeking pole of the needle more than the south-seeking pole, but it is convenient to determine the direction in which a needle faces by stating the direction in which its north-seeking pole faces. If the lines of force mapping the different directions of strain in the ether be followed from the north-seeking pole of the bar magnet until they enter the south-seeking pole, the north-seeking pole of the needle at every part of this entire path will point forward, while the south-seeking end of the needle points backward.

In order to facilitate the ready determination of the direction assumed by the compass needle, it may be *imagined* that the lines of force *leave the north-seeking end* of the bar magnet and, after curving through the field, *enter at the south-seeking end.* In this case the rule may be given that the north-seeking ends of small movable magnets placed within the field of a larger magnet are always urged to face in the direction in which the nearest lines of force are passing. But it should be remembered

that actual lines of force do not exist. What we call lines of force are merely useful drawings by means of which we record the changes in direction of the strain in the ether. It will sometimes be found convenient to refer to lines of force as though they really existed, but a failure to understand their real nature as imaginary lines mapping the direction of strain in the ether and not as lines having actual existence will result only in a confusion of fact and fancy during the study of the phenomena of magnetism.

280. Magnetic Induction.—Place a pane of glass on a soft-iron bar about $2\frac{1}{2}$ inches long. Sprinkle iron-filings evenly over the surface and tap the glass. No change occurs suggesting the presence of magnetism in the iron bar.

Place the glass over the north-seeking end of a bar magnet, sprinkle filings, and again tap the glass. The filings now appear to be arranged in lines which radiate from the north-seeking pole of the magnet, curve around its sides and then enter from all directions at the south-seeking pole. It is this appearance that first suggested the idea of lines of force. The lines indicate in what direction the ether in the field around the magnet is strained.

The ether within the body of the magnet is also strained. Lines of force therefore should be drawn so as to indicate both the direction of the strain of the ether in the field around the magnet and also of the ether within the body of the magnet. Lines of force drawn in this manner appear to traverse complete circuits (not circles). They may be imagined to pass from the north-seeking pole through the field toward the south-seeking pole, and then to complete their circuits by passing through the body of the magnet from the south-seeking pole toward the north-seeking pole. An examination of the lines in-

dicated by the iron-filings will show that poles are not definite points at the ends of magnets, but rather indefinite regions, near the ends, from which the lines appear to radiate, or toward which they appear to converge.

Lift the pane of glass carefully, so as not to disarrange the filings. Fold a piece of paper neatly over the north-seeking end of the magnet, and press this end of the magnet against a soft-iron bar. The paper prevents actual contact between the magnet and the soft iron. Then replace the glass, lowering it carefully so that the appearance of lines of force radiating from the north-seeking pole of the magnet is restored. Again tap the glass. The filings rearrange themselves, and many lines of force now appear to radiate from the sides and farther end of the soft-iron bar as well as from the end of the magnet. This indicates that the ether within and around the soft-iron bar now is also strained. It should therefore show the same magnetic properties as the magnet, although possibly in a lesser degree. This may be readily demonstrated by placing the farther end of the soft-iron bar in a pile of tacks while the north-seeking pole of the bar magnet with its paper cover is still held against the other end of the bar. In this condition the soft-iron bar picks up tacks.

As soon as the magnet is withdrawn from the soft-iron bar, the tacks drop off. After the removal of the magnet, cover the soft-iron bar with the pane of glass, sprinkle iron-filings, and tap the glass. As might be expected from the dropping off of the tacks when the magnet is removed, no appearance of lines of force is produced around the soft iron when not in the immediate vicinity of the magnet.

The magnet is said to *induce* magnetism into the soft-

iron bar. Since soft iron does not retain magnetism well, the bar is only temporarily a magnet. It should scarcely be necessary to state that the strain in the ether as shown by the iron-filings is not due to the tapping of the glass. The tapping merely assists the iron-filings in rearranging themselves so as to make evident any magnetic strain which may be present in the ether.

281. Magnetic Permeability of Soft Iron and Air.—It was seen in the preceding experiment that the filings re-arranged themselves after the soft-iron bar had been added to the magnet and the glass had been again tapped.

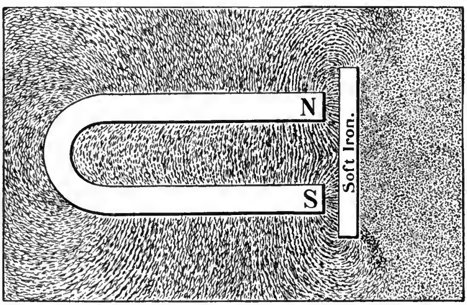


Fig. 120.

This indicates that the presence of soft iron within the field of a magnet changes the direction of the strain of the ether within the field. This may also be shown by other experiments.

Place a bar of soft iron a short distance in front of the poles of a large horseshoe magnet. Cover bar and magnet with a pane of glass and place a second bar of soft iron directly over the first. Sprinkle iron-filings evenly over the surface and tap the glass. Notice to what extent the lines formed by the iron-filings may be distinctly traced beyond the soft-iron bars (Fig. 120). Now gently raise

the glass, remove both soft-iron bars, and carefully replace the glass in its original position over the magnet. Tap the glass again. The lines, formed by the filings, passing from the north-seeking to the south-seeking pole, may now be traced distinctly to a much greater distance in front of the magnet (Fig. 121). This suggests that in the first case the soft-iron bars change the direction of the strain in the ether in the field in front of the magnet, and also distinctly weaken the strength of that part of the field which lies beyond the soft iron. Instead of a horseshoe magnet, two bar magnets may be used. Place

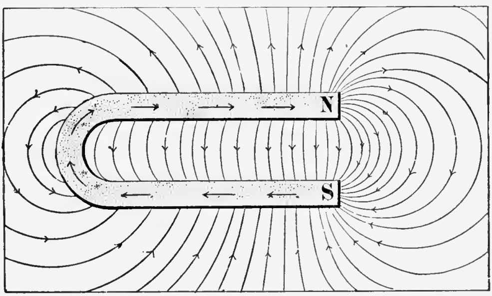


FIG. 121.

the magnets side by side, about 3 inches apart, with the like poles pointing in opposite directions. Use one pair of poles.

This principle has been found useful to a certain extent in protecting the works of a watch from magnetism. If the case of a watch be constructed of soft iron, the part of the field enclosed within the case is much weaker and the works are in a measure protected. The appearance of the watch is of course improved by plating the case with gold.

A study of the preceding experiments suggests not only

that soft iron alters the direction of the strain in the ether in the field surrounding a magnet, but that it appears to take up a large part of the strain in this part of the field, leaving the ether beyond in a less strained condition. On this account soft iron is said to be more *permeable* to magnetism than air.

282. Physical Theory of Magnetization.—Magnetize a straightened piece of a broken watch-spring, such as may be obtained from any jeweler. Dip the entire piece under iron-filings; on its removal iron-filings adhere to the ends but not to the middle. This shows that for the greater part of the length of the magnetized watch-spring the strain of the ether lies chiefly within the body of the spring and is practically parallel to its length. At the ends of the spring where the filings adhere the direction of this strain changes. When studied in connection with iron-filings the appearance is as if lines of force pass out and enter chiefly at the ends of the magnet.

With a wire nipper, cut the straightened spring at a point where no filings adhere. On dipping in iron-filings, filings are found to adhere at the cut end. The lines of force now appear to come out at a part of the magnetized spring where a moment before no magnetism was shown. This indicates a change in the direction of the strain at the point where the spring was cut. Continue the cutting, and even the smallest fragment of watch-spring will show magnetism at each end. In each case the part remaining appears to be a complete magnet, but smaller and weaker. It is possible to conceive that this cutting might be continued indefinitely and that if a single molecule of iron could be secured, each end of this molecule would show magnetic properties, one end being north-seeking and the other end south-seeking.

In accordance with this view a magnet consists of a combination of many magnets, each molecule being a tiny magnet. If the north-seeking ends of several magnets are held together, their combined effect is greater than that of any one of the magnets. In the same manner, many millions of molecules of iron with their north-seeking poles all directed in the same direction ought to show considerable magnetism (Fig. 122, A). If these molecules became considerably disarranged, the north-

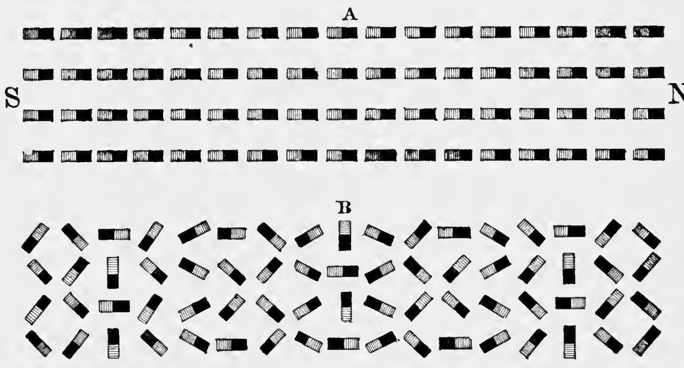


FIG. 122.

seeking poles and the south-seeking poles might counteract each other (Fig. 122, B). This principle may be illustrated by laying the north-seeking pole of one magnet upon the south-seeking pole of another and then trying to lift up tacks while these ends are in contact with one another. It will be found that in this condition the magnets will lift up less tacks than if either magnet had been used alone. In fact, it frequently happens that when the north-seeking and south-seeking poles are used together, scarcely any tacks can be lifted.

According to this theory, the magnetizing of an iron or steel bar consists simply in drawing the corresponding ends of all the molecules in the same direction by stroking the bars of which they are a part by means of some strong magnet, always in the same direction. The like poles of the molecules are thus caused to face in the same direction. In this position they act together as a unit. Twisting the magnetized bar, pounding it, or heating it, considerably disarranges the molecules. The poles of the molecules now face in so many directions that they counteract each other, and the bar no longer shows pronounced magnetic effects. The bar is said to be *demagnetized*.

STATIC ELECTRICITY

283. Electrification by Rubbing.—Suspend a pith ball, a quarter of an inch in diameter, at the end of fine silk thread about ten inches long. Hold the end of an ebonite rod near the pith ball. The pith ball is not affected in any manner by the presence of the ebonite rod. Now rub the end of the ebonite rod with flannel and bring it near the pith ball. The pith ball is at first attracted, but, after contact has been broken, it is repelled (Fig. 123). Rubbing has given the ebonite rod some properties which it did not possess before. The rod is said to be *electrified*.

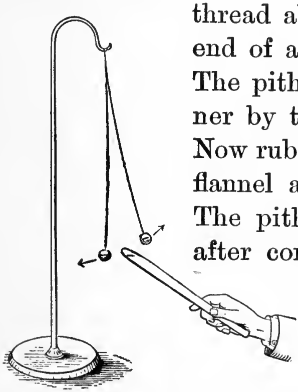


FIG. 123.

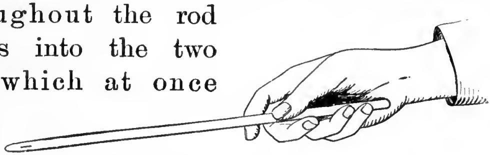
284. Electrification by Contact with an Electrified Body.—Suspend two pith balls at the same level by means of

two silk threads. Bring the upper ends of the threads in contact with each other. The pith balls strike against one another and show no unusual properties. Now bring a strongly electrified ebonite rod into contact with the pith balls. Withdraw the rod and again hold together the upper ends of the silk threads. The pith balls remain apart, showing that they repel each other. The pith balls, in this case, have become electrified, not by rubbing, but by contact with a body which was electrified. In this condition, the pith ball is often said to be *charged* with electricity, and the experiment indicates that *two bodies electrified in the same manner repel each other.*

285. Conductors.—Suspend two pith balls from a glass support by silk threads which are tied together at the top, thus bringing the pith balls at the lower ends of the threads in contact with one another. If the silk threads are touched at their upper ends with a strongly electrified ebonite rod, the pith balls remain in contact. If the experiment be repeated with balls suspended by cotton thread, the pith balls repel each other strongly. This indicates that cotton *conducts* electricity fairly well from the electrified ebonite rod to the pith balls, but silk is evidently a very poor conductor.

286. The Electroscope.—A pair of pith balls suspended at the lower ends of cotton threads, tied together at the top, may be used to detect the presence of electricity in a body. The mutual repulsion of the pith balls on bringing any object in contact with the cotton threads at once indicates that the object is electrified. There are, however, much better conductors than cotton, and much lighter bodies than cotton thread and pith balls. By means of these bodies it is possible to detect much

lighter charges of electricity than by means of the thread and pith balls. All metals are better conductors of electricity than cotton. Several of these metals can be secured in the form of exceedingly thin sheets. Tin, aluminum, and gold foil are examples of metals in this form. When sufficiently thin, sheets of these metals are so light that they move at the slightest breath of air. If two thin strips of foil are fastened at the lower end of a metal rod, and an electrified body is brought into contact with the supporting rod, the electricity spreads readily throughout the rod and a part passes into the two strips of foil which at once repel each other. The strips of foil are so light, that bodies, which are so weakly electrified that contact with pith balls produces no perceptible repulsion, will, when brought in contact with the supporting rod, cause the strips of foil to repel each other violently.



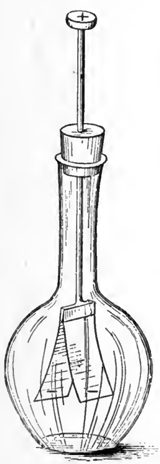


FIG. 124.

This principle is used in the construction of an instrument for the detection and study of charges of electricity, called the *electroscope* (Fig. 124). This consists of a brass rod with a knob at the top, passing through a rubber stopper into a flask. The lower end is broadened and serves as the place of attachment of two thin strips of gold leaf. If an electrified ebonite rod is brought in contact with the knob, the electricity passes down the brass rod into the gold leaves, and consequently the gold leaves repel each other.

287. Electricity Passes from Points of Strong Electrification to Points of Less or No Electrification.—If a slightly electrified ebonite rod is brought in contact with the electroscope, the gold leaves diverge slightly. If a more strongly electrified rod is used, the gold leaves diverge more. If an electroscope with strongly diverging gold leaves is brought in contact with an unelectrified electroscope, by means of a long copper wire, the leaves of the second electroscope diverge. If by the

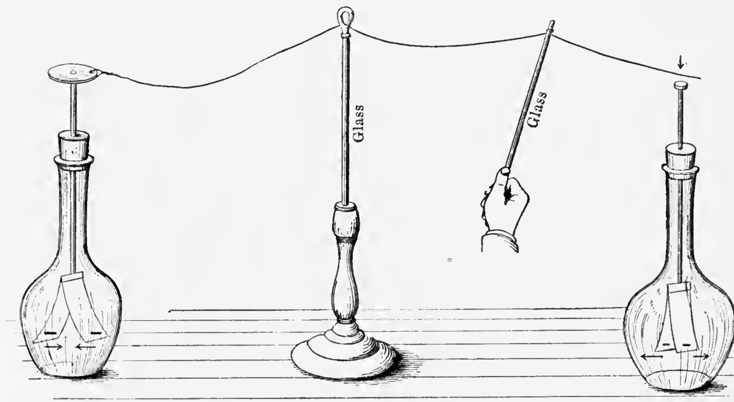


FIG. 125.

same means a strongly electrified electroscope is brought in contact with a moderately electrified electroscope, the strongly diverging leaves of the first electroscope collapse partly, while those in the second instrument diverge more (Fig. 125).

In performing these experiments, the copper wire must not be allowed to come in contact with the table, the hand, or any other material which will conduct electricity. It may be handled most readily by twisting the wire around glass rods which may be held in the hand.

These experiments show that electricity passes from points of strong electrification to points of less or even of no electrification. Whatever may be the true nature of electricity, this transfer of electricity must be due to some force or to a relative inequality of forces residing in different objects. In the last experiment both the electricity in the strongly electrified electroscope and that in the less electrified instrument tend to move away from these objects to points of still weaker electrification. However, when the two are brought in contact with one another by means of the copper wire, the electricity appears to move from the more electrified to the less electrified body, and the force with which it moves must unquestionably depend upon the difference of the two forces urging the electricity in the two electroscopes toward some other point.

288. Potential, Electromotive Force.—The force with which the electricity in each electroscope tends to move to some other point, is called the *potential* of the electricity in that instrument. The force with which a part of the electricity in the more highly charged instrument is urged to move from this electroscope to the one less strongly charged, is due to the *difference of potential* between these instruments. The force with which a part of the electricity moves in consequence of this difference of potential is often spoken of as though it were a single separate force, instead of an effect due to the difference in strength of two forces, and is then called the *electricity moving force*, or the *electromotive force.*

289. Electrification Caused by Contact of Two Different Substances.—In the preceding experiments, ebonite was electrified by rubbing it with flannel. Many other bodies may be electrified in a similar manner. Glass is fre-

quently electrified by rubbing it with silk. In fact, the rubbing together of any unlike substances at once results in electrification. Rub the coat sleeve vigorously over a piece of paper and place the paper against the wall. It adheres to the wall, showing that it has become electrified. Rub another piece over the varnished surface of a school-room desk, and the paper will show less tendency to slide down the inclined surface than it exhibited before it was rubbed. From this it might appear that rubbing is essential to the electrification of objects.

It is becoming evident, however, from more recent observations, that the essential element in electrification is mere contact between unlike bodies. Mere contact between ebonite and flannel produces a state of electrification, but, since both ebonite and flannel are very poor conductors of electricity, it is difficult for electricity to spread from the points touched to other parts, and the state of electrification is therefore practically confined to points of actual contact. Rubbing brings many more points on the ebonite rod in actual contact with many parts of the flannel, and hence the degree of electrification of the rod is very much increased by rubbing.

Moreover, since ebonite is a non-conductor, only the end rubbed shows evidence of electrification; but if one end of a good conductor, such as a brass rod, is rubbed, the entire rod gives evidence of electrification. In order to prevent the escape of electricity through the hand, the brass rod must, of course, be held by means of some non-conducting material—for instance, at the end of a glass rod, or by means of a piece of silk.

CURRENT ELECTRICITY

290. A Continuous Current of Electricity Maintained by Chemical Action.—Whenever any solid is brought in contact with any liquid, for instance, by dipping the solid in the liquid, the solid is electrified. The evidence of electrification may be made especially clear if both solid and liquid are good conductors. When any two solid conductors are dipped into the same liquid conductor, they will, as a rule, be found to differ in their degree of electrification. Hence, the charges of electricity in the two solids will be at a different potential, or will differ in the force with which they tend to move to other points. In consequence of this difference of potential, the electricity tends to move from the point of higher potential to that at lower potential, as soon as the solid conductors are joined by means of wire which is also a conductor. The result is a current of electricity.

It does not differ essentially from the current of electricity produced by two electroscopes electrified to different potentials, connected by means of a conducting wire.

When a strongly electrified electroscope is connected with a weakly electrified electroscope, the current of electricity lasts only an instant while the potentials in the two electroscopes are being equalized. This takes place so quickly that the current is only momentary. When, on the contrary, two different solid conductors are dipped in a liquid conductor which attacks at least one of them chemically, the chemical action keeps up a difference of potential in the two solids, even after they have been connected a long time by the wire. It may be that chemical action results in a continual renewal

of contact between the solids and the molecules of the liquid, so that the inequality of the charges of electricity in the solids is renewed as rapidly as these charges are equalized by the connecting wire. In other words, owing to chemical action, there is a continuous current of electricity through the wire.

291. The Electric Cell.—When copper and zinc are dipped into dilute sulphuric acid, both copper and zinc are electrified; the potential of copper, where in contact with the air, is higher than the potential of that part of the zinc which extends up into the air. Hence a current of electricity flows from the copper through the wire to the zinc, as soon as these metals are connected by means of wire (Fig. 126).

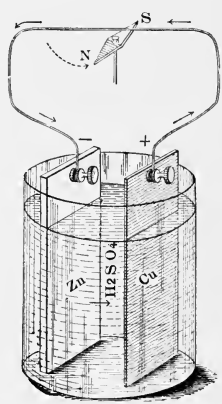


FIG. 126.

The zinc is attacked by the sulphuric acid. It continues to be attacked even after the flow of electricity through the connecting wire has been started. In consequence of this continued chemical action, the difference of potential between the copper and zinc is kept up, and the flow of electricity continues. The zinc gradually wears away and must be replaced from time to time. The sulphuric acid solution must also be replenished.

Instead of copper, carbon is frequently used, and instead of sulphuric acid, sal ammoniac, copper sulphate, or a mixture of sulphuric acid and potassium bichromate is often employed. The combination of copper and zinc, or of copper and carbon plates with the chemical solution, including the jar containing the solution, is usually called an electric cell or battery.

The sal-ammoniac cell is the cell most frequently used for electric bells and buzzers. It consists of zinc and carbon plates, rods, or cylinders dipped into a solution of sal ammoniac.

In the cell commonly used for telegraphic instruments, the gravity cell (Fig. 127), the metals employed are zinc and copper. The copper, in the form of thin sheets, is placed in the bottom of the cell, and the zinc is suspended in the upper part of the liquid. When the zinc is cast into the form of diverging bars, it slightly resembles the spreading toes of some birds, and in that case the gravity cell is often called a crowfoot battery. Crystals of copper sulphate are thrown into the water and dissolve. After the cell has been used a short time, zinc sulphate is formed. The solution of zinc sulphate is lighter than that of copper sulphate, and therefore rises to the top of the cell. The contrast between the colorless zinc sulphate solution and the blue copper sulphate solution beneath is very distinct in a cell which has been in use for several days. The zinc sulphate is in contact with the zinc plate. The copper sulphate is in contact with the sheets of copper. The chemical action is complicated. The zinc wears away. The copper in the copper sulphate becomes separated from the copper sulphate and settles on the copper plate. The copper plate, therefore, increases in thickness, but the

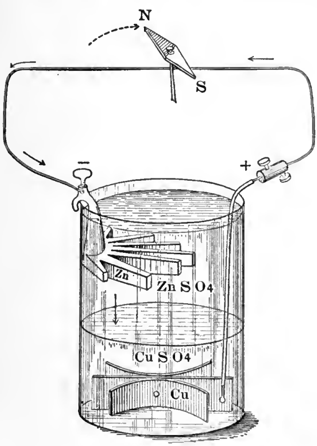


FIG. 127.

copper sulphate in the solution must be replenished from time to time by the addition of more copper sulphate crystals.

The potassium bichromate cell consists of carbon and zinc plates placed in a solution consisting of sulphuric acid, potassium bichromate, and water.

The plate having the higher potential, usually copper or carbon, is called the *positive plate.* The plate having the lower potential, almost invariably zinc, is called the negative plate. For the purpose of connecting wires to these plates, binding posts are added. The current starts on that part of the copper or carbon plate which is out of the liquid, passes through the wire to the zinc plate, and then returns through the liquid to the copper or carbon plate.

ELECTROMAGNETISM

292. Compass Needle Affected by a Wire Bearing an Electric Current.—Connect the carbon plates of four potassium bichromate cells to one another by means of wires. Connect in the same manner the four zinc plates. Any wire connecting one of these carbon plates with one of the zinc plates will now conduct the electricity from all of the carbon plates to the zinc plates. The four cells now act like one huge cell. Cells arranged in this manner are said to be *connected in parallel.* Use a connecting wire about five feet long, and fasten a length of about one foot in such a manner that the current will pass vertically upward. Bend the remainder of the wire so as to keep it as far distant from this length as possible.

The plates of potassium bichromate cells are usually

so arranged that all the plates can be raised at the same time from the jar (Fig. 128). The plates are raised to prevent the liquid from attacking the zinc plates when the cells are not in use. While in this condition no current can flow through the wire. Hold a small compass, not more than an inch in diameter, on various sides of the

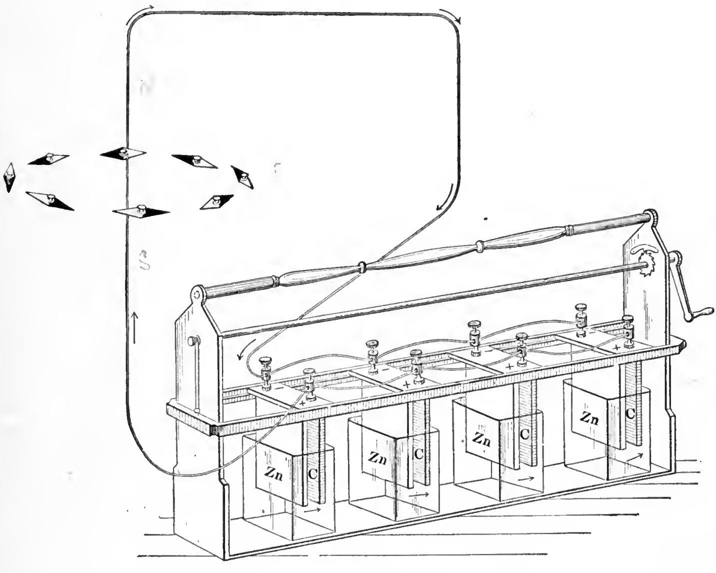


FIG. 128.

vertical part of the wire. In all positions of the compass the needle points northward. Lower the plates into the liquid and the needle now points southward on the west side of the wire, eastward on the south side, northward on the west side and westward on the north side. If intermediate points be tried, the needle will be found to point in intermediate directions. In conse-

quence of the electric current some force evidently urges the needle of the compass to occupy positions at variance with its usual position when held at a distance from objects conducting electric currents.

293. A Magnetic Field Encircles a Wire Bearing an Electric Current.—It has already been shown that bar magnets are able to influence the direction of the compass needle (§ 277). It is believed that this influence is due to a strain in the ether in the field surrounding the magnet. The direction of strain of the ether in a magnetic field may be indicated by lines called lines of force. In the field of a magnet the strain is represented by lines leaving in all directions at one pole, curving around through the air, entering from all sides at the other pole, and traversing the length of the magnet, thus forming complete circuits.

The experiment with the compass needle held near a wire carrying a current of electricity (§ 292) suggests that the ether is strained also in the field surrounding a wire while an electric current is passing. The different positions occupied by the compass needle indicate that the lines of force representing this strain must be drawn in the form of circles surrounding the wire. This may be shown also by means of iron-filings, sprinkled on a sheet of card-board. If a wire is passed vertically through the card-board and a heavy current is turned on, a slight jarring of the card-board causes the filings to arrange themselves in circles surrounding the wire (Fig. 129). No part of the path of these lines of force passes through the wire; nothing corresponding to poles exists, and

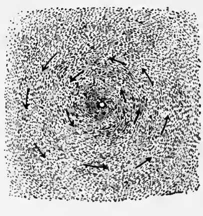


FIG. 129.

hence there is no radiation of lines of force as at the poles of magnets. If a very small compass needle is held at various distances from the wire, it becomes evident that the magnetic influence of the current is greatest in the immediate vicinity of the wire, and becomes rapidly less as the distance from the wire increases. This may be represented by diminishing the number of lines of force as the distance from the wire increases.

The direction assumed by a compass needle in the field of a magnet may be determined mechanically by the rule that the needle points forward at every part of any line of force if followed from the north-seeking to the south-seeking pole.

There is also a convenient mechanical rule for determining the direction assumed by a needle placed in the magnetic field of a wire carrying a current. If the wire is grasped by the right hand so that the fingers encircle the wire and so that the thumb points in the direction in which the current is flowing, the tips of the fingers will point in the direction in which the north-seeking pole of the needle will face if placed on the same side of the wire. From this thumb and finger rule it is at once evident that if a current is sent downward through a vertical wire, the lines of force must travel around the wire in a direction exactly opposite to that followed when the current is sent upward through the same wire. Hence all the positions of the compass will be reversed. Show this by actual experiment.

294. Direction of Current Determined by Means of the Compass.—If a wire is held in a horizontal position directly above a needle so that the current passes northward over the needle, the thumb and finger rule given in the preceding paragraph indicates that the north-seeking end of

the needle must turn westward. If the current is sent southward over the needle, the north-seeking end of the needle turns eastward.

Determine in what direction the needle will point if you send the current northward under the needle, or if you send it southward beneath the same. In what direction do the lines of force pass on the *side* of the wire when the current passes northward? When the current passes southward?

295. A Loop through which an Electric Current is Passing Behaves like a Magnet.—Bend the wire connected with the potassium bichromate cells in such a manner that a part of it forms a single horizontal loop, and so that the current goes westward along the northern curve of the loop (Fig. 130). Making use of the thumb and finger rule, and representing the direction of the strain in the ether around the wire by means of lines of force, it will be seen that the lines of force come upward at all points along the interior of the loop, curve around the top of the wire, pass downward along the outer part of the loop, and re-enter at the lower face. In this form of representation the lines of force leave the upper face of the loop and radiate in all directions just as they leave the north-seeking pole of a magnet. At the lower face of the loop the lines of force re-enter, as is true also of the lines of force at the south-seeking end of the magnet. In both cases the lines of force indicate merely the direction of the strain in the ether, and the direction toward which

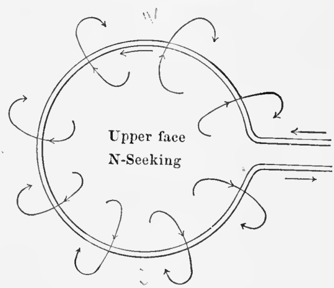


FIG. 130.

the north-seeking end of the compass needle within the field points. Therefore the character of the strain of the ether on the upper face of the loop is similar to the strain at the north-seeking pole of a magnet. From this it might be expected that the upper face of the loop ought to possess magnetic properties similar to the north-seeking pole of a magnet, while the lower face should possess properties similar to those of a south-seeking pole.

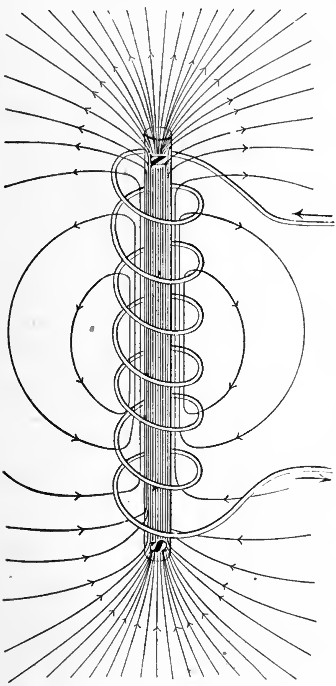


FIG. 131.

If the current of electricity is sent in an opposite direction around the loop, or if the wire is coiled so that the current passes in an opposite direction, the upper face of the loop becomes south-seeking, and the lower north-seeking.

296. The Electromagnet.—Bend a wire so as to produce a succession of horizontal loops forming a long, close coil. If the ends of the wire be connected with the potassium bichromate cells so that the current goes westward along the northern curve of the loops, the upper face of each loop will tend to be north-seeking while the lower face will be south-seeking (Fig. 131). The combined effect of the different loops is such as to cause a considerable in-

crease in the strain of the ether, especially along the interior of the coil. This is represented diagrammatically by drawing the lines of force in such a manner that many of the lines of force pass from loop to loop lengthwise through the centre of the coil, thus increasing the total number of the lines of force passing upward through the centre of the individual loops.

We have already learned that soft iron is much more permeable to magnetism than air. The ether within the soft iron appears to be strained more readily than the ether in the surrounding air. The result is that, if a bar of soft iron is placed lengthwise along the centre of the coil, the strain of the ether along the interior of the coil is much increased, and the magnetic effects exhibited at the ends where the soft iron projects are also greatly strengthened. This may be represented diagrammatically by increasing the number of lines of force traversing the length of the coil when soft iron is placed along its interior. The combination of the coil with the soft-iron core shows, therefore, far greater magnetic properties at the end of the coil than when the coil is used alone.

The end of the coil or of the soft iron within the coil from which the lines of force are represented as coming out, acts like a north-seeking pole of a bar magnet. The opposite end at which the lines of force are represented as coming in, acts like a south-seeking pole.

A modification of the thumb and finger rule will enable any one quickly to determine the magnetic properties of the poles of any coil through which a current is passing. Place the thumb along one of the loops of the coil in such a manner as to point in the direction in which the current is passing. Imagine that the fingers grasp the wire

of this loop, but that the tips of the fingers lie within the centre of the coil. The end of the coil toward which the finger tips would point is the north-seeking end of the coil. This may be easily tested by means of a compass needle, whose north-seeking pole should be repelled by this end of the coil as long as a current of electricity is passing.

It should be noted that the strain in the ether in the field around a wire is dependent entirely upon the presence of a current in the wire. When there is no current, the ether is not strained. The coil containing the soft iron is therefore a magnet only while a current of electricity is passing through the coil. For this reason the combination of the coil with its soft-iron core is called an *electromagnet.*

If the coil consists of many loops and if a sufficient current of electricity is passed through the coil, an electromagnet can be made much more powerfully magnetic than any permanent steel magnet of the same weight. Electromagnets are employed for many instruments (electric bells, telegraph instruments) in which it is necessary that the magnets employed should be magnetic only temporarily. In these cases, permanent magnets would be useless.

Electromagnets are usually made in the form of two short coils, traversed lengthwise by pieces of soft iron. These pieces of soft iron are connected at one end by a transverse piece, thus having a slight resemblance to a permanent horseshoe magnet. The object to be attracted usually consists of a fourth piece of soft iron held a short distance away from the poles of the electromagnet by a spring. This movable piece of soft iron is called the *armature.* Most of the lines of force from the

north-seeking pole of the electromagnet pass through the air to the nearest part of the armature, through the armature, thence from the other end of the armature through the air to the south-seeking pole of the electromagnet, and then return through the soft iron to the north-seeking pole.

As soon as a current of electricity is passed through the coils of the electromagnet, the armature is attracted. The instant the current of electricity is broken, the elec-

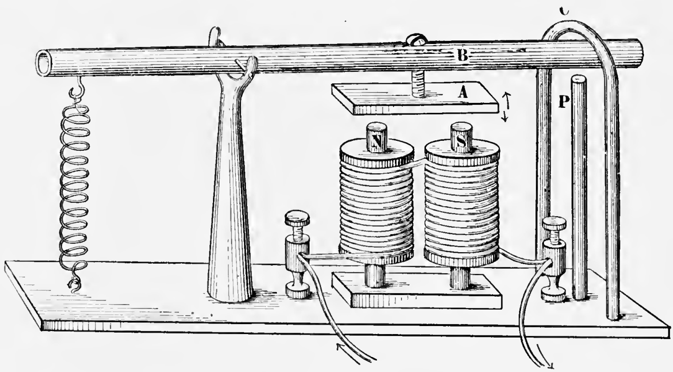


FIG. 132.

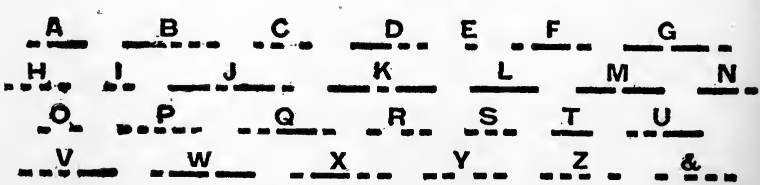
tromagnet loses its magnetism and the spring attached to the armature draws the armature away.

297. The Sounder Used in Telegraphy.—In the sounder, an instrument used in telegraphy (Fig. 132), the poles, N S, of the electromagnet face upward and the armature, A, attached to a short horizontal brass tube, is placed directly over the poles. Ordinarily the armature is kept at a short distance from the electromagnet by a spring attached to the farther end of the brass tube. As soon as a current of electricity is passed through the electromagnet, the armature is drawn down and the end

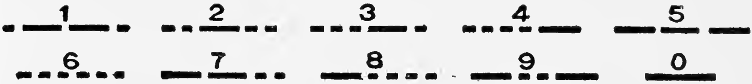
of the brass tube to which the armature is attached strikes against a vertical post, P, and the instant the current of electricity ceases, this end of the brass tube is drawn up by the spring at the opposite end already mentioned, and strikes against the lower side of a brass arch, C. The clicks against the vertical pillar and those against the arch differ so much in the character of the sound that they may be easily distinguished. By means of these sounds, it may be readily determined how often and for what length of time the current of electricity has been passed through the electromagnet.

In telegraphy, a current of electricity sent through the electromagnet for a short time is represented by a dot. One sent through for a longer time is represented by a dash. And one sent through for a still longer length of time is represented by a dash twice or three times as long. The various letters of the alphabet, the Arabic numerals, and the signs used in punctuation, are represented by a combination of such dots and dashes. Any one expert enough to recognize from the various clicks how often and for what length of time the current of electricity was sent through the electromagnet of the sounder, can easily determine what letters, figures, and signs it is desired to convey by means of the telegraph.

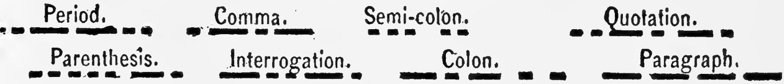
The following table represents the system in ordinary use:



NUMERALS.



PUNCTUATION.



298. The Relay Used in Telegraphy.—When the distance to be telegraphed is very great, the resistance of the telegraph wire to the passage of the current of electricity may be so great that the electromagnet of the sounder

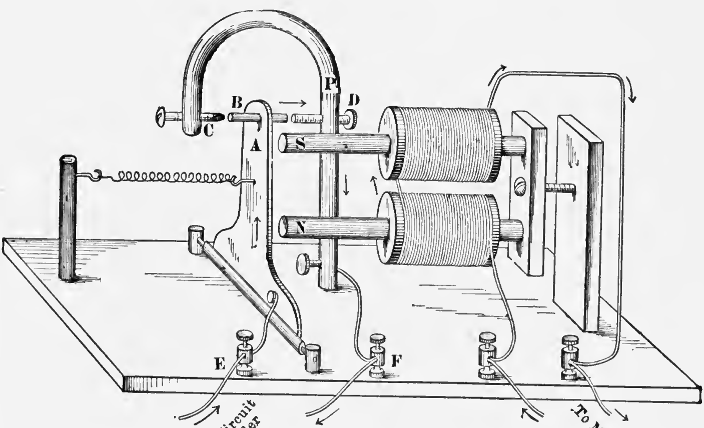


FIG. 133.

does not become magnetic enough to pull down the armature in opposition to the action of the spring which tends to hold the armature up. In that case another instrument is used called the *relay* (Fig. 133). This instrument is essentially like the sounder. The electromagnet

of the relay is, however, fastened in a horizontal position. The armature, A, is a thin vertical piece of soft iron supported by a horizontal brass bar in such a manner as to be readily movable. Ordinarily a very light spring draws the armature a slight distance away from the electromagnet. However, as soon as a current of electricity passes through the electromagnet, the armature is drawn over towards the magnet, N S.

Through the upper end of the armature of the relay passes a small platinum peg, B. This peg during its forward and backward motions strikes against the tips of two horizontal screws, C D, passing through the upper end of a brass post bent at the top into the form of an arch, P. The clicks against these screws, although faint, may be used for purposes of telegraphy just as were the much louder sounds produced by the horizontal brass tube in the case of the sounder. In order to make the electromagnet of the relay as strong as possible, notwithstanding the weak currents passing through the wires, the coils of the electromagnet are made of many turns of fine wire. By using fine wire it is possible to get many more turns of wire on the same electromagnet and the magnetic strength of the electromagnet is much increased.

In actual practice the clicks of the armature in case of the relay are never used for purposes of telegraphy. But when the armature of the relay touches the screw, D, on the side nearest the electromagnet it completes the path for a second current of electricity which passes through a second circuit whose total length is usually only a few feet. In this second circuit, by means of the connections at E and F, are placed an ordinary sounder and also an electric cell, so that whenever a current of electricity

passes through the electromagnet of the relay, the touching of the platinum peg in the armature against the metal tipped screw permits a current to pass from the cell through the sounder. When no current passes through the electromagnet of the relay, the armature, A, is not attracted: It may then be drawn away from the electromagnet by the weak spring. This stops also the current in second or local circuit. Even if the platinum tip, B, strikes against the screw, C, no current can flow since the tip of this screw is made of ebonite, a non-con-

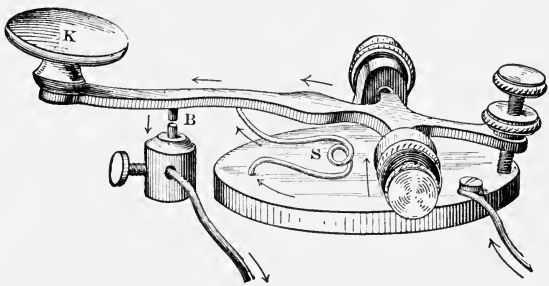


FIG. 134.

ductor (§ 317) of electricity. On account of the short length of the second circuit, the current of this circuit is much stronger. The sound produced by the sounder is much louder than that produced by the relay, and the sounder is the only instrument to which the telegrapher pays any attention.

299. The Telegraph Key.—In order to start and to stop the current of electricity quickly whenever desired, a telegraph *key* (Fig. 134) is used. This is so constructed that when the key is pressed down there is no break in the path of the electricity. But when the finger is raised,

the key is thrown up by a spring, S, there is a break in the circuit at B, and the current ceases to flow.

300. The Earth Forms a Part of the Circuit for the Electric Current Used in Telegraphy.—A single wire may connect all the stations for a distance of several hundred miles. In this case, the ends of the wires at the extreme stations are connected with metal plates buried so deep in the ground that they are always moist (Fig. 135). The electricity then passes from the electric cells to the extreme end of the wire into the ground and then returns through the moist earth by way of the plate at the opposite end of the line. That part of the circuit which is formed by the earth is usually known as the ground circuit.

301. A Message Can Be Heard at all Stations on the Same Line.—Since all the relays at all of the stations are connected by the same wire (Fig. 135), when one sounder is heard all the sounders at the other stations on the same line are also in operation. Any message heard at one station may therefore also be heard at all of the others. Unless called for by his particular number, the telegrapher need pay no attention to the message sent.

302. Arrangement of Electric Cells for Telegraphic Purposes.—When it is desired to send a current of electricity through a long wire or through anything which offers a great resistance to the passage of the current, the cells are arranged in *series*. In this case the zinc in each cell is connected with the copper or carbon of the next cell in such a manner that the current of electricity must pass from cell to cell before it can get out into the main wire (Fig. 135, explanatory drawings). When it is desired to produce a strong current through a short wire, or through

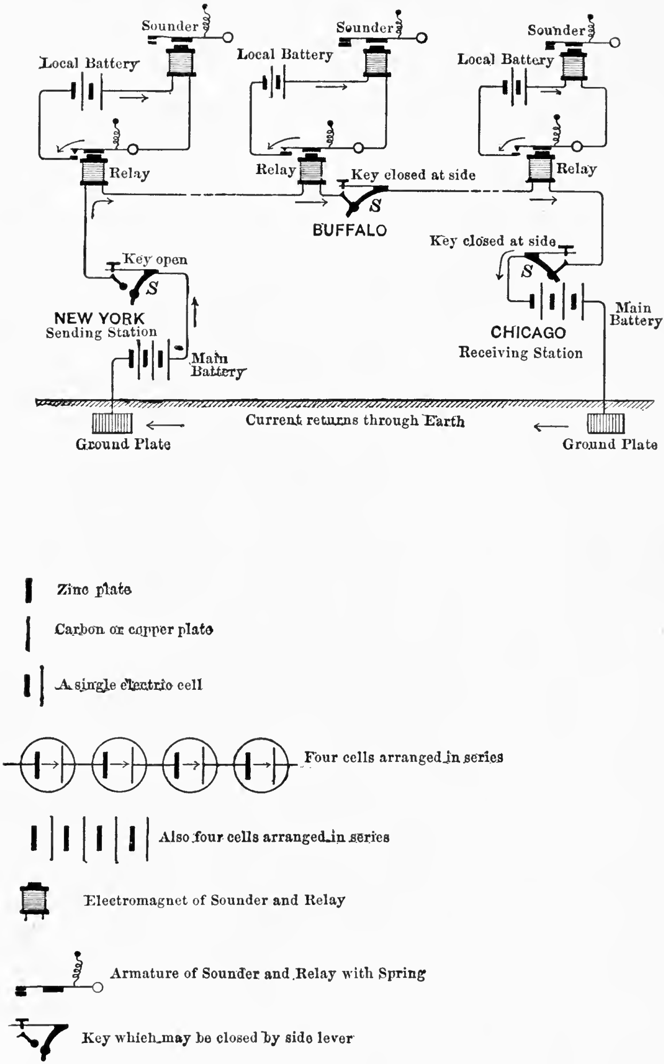

Sounder
Local Battery
Relay
Sounder
Local Battery
Relay
Key closed at side
S
BUFFALO
Sounder
Local Battery
Relay
Key open
S
NEW YORK
Sending Station
Main Battery
Key closed at side
S
Main Battery
CHICAGO
Receiving Station
Current returns through Earth
Ground Plate
Ground Plate
Zinc plate
Carbon or copper plate
A single electric cell
Four cells arranged in series
Also four cells arranged in series
Electromagnet of Sounder and Relay
Armature of Sounder and Relay with Spring
Key which may be closed by side lever

Fig. 135.

anything offering little resistance, the *parallel* arrangement of cells is used (Fig. 128). For purposes of telegraphy a number of gravity cells arranged in series is commonly employed.

303. The Electric Bell.—For ringing an electric bell any kind of sal ammoniac cell will do. Instead of a key, a push button is used, which is more simple in construction than

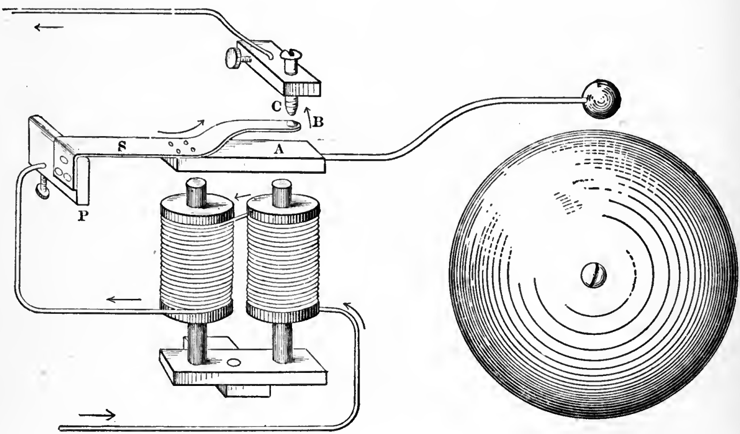


FIG. 136.

the telegraph key, but serves for exactly the same purpose, to open and to close the circuit.

In the electric bell (Fig. 136), the armature, A, is held by a spring, S, a short distance away from the poles of the electromagnet. The spring consists of a flat strip of brass, one end of which is fastened to a metal post, P, and the other end is narrowed and so bent that when there is no current in the electromagnet, the narrowed end of the spring, B, presses against the tip of the screw, C. The current after passing through the electromagnet enters

the post supporting the spring, P, to which the armature is fastened. It passes along the spring, S, to the narrowed end, B, and there it enters the screw, C.

As soon as the current passes through the electromagnet, the electromagnet becomes magnetic, attracts the soft-iron armature, A, notwithstanding the action of the spring, and in this manner draws the narrowed end of the spring away from the screw. As soon as the tip of the spring leaves the screw, the path of the current is broken, the flow of electricity ceases, the electromagnet is no longer magnetic, the armature is no longer attracted, and the spring to which it is attached, on assuming its original position, throws the armature back. This, however, brings the tip of the spring against the screw, the current is re-established, and the armature is once more attracted. The armature continues to fly back and forth as long as the hand is pressed against the push button. A tapper is attached to the end of the armature and a bell is placed on the same side as the electro-magnet. Whenever the armature is drawn over, the tapper strikes against the bell.

304. Galvanometers.—If a wire is bent around a compass so that the current goes northward over the needle and southward under the needle, both the current above the needle and the current below the needle will tend to throw the north-seeking end of the needle westward. This may be easily shown by applying the thumb and finger rule for both parts of the wire. If the direction of the strain in the ether around the wire above and below the needle be represented by lines of force, it is evident that the lines of force due to both the current above and below the needle will point in the same direction within the space between the wires where the needle is

situated. The wire bent in the manner directed forms a single loop. If instead of a single loop a great many turns of wire are taken the current will pass frequently northward over the needle and southward under the same, and the north-seeking end of the needle will be thrown farther toward the west.

In the case of any given coil, the amount of deflection of the needle toward the west will increase with the increase in strength of the current. Upon this principle

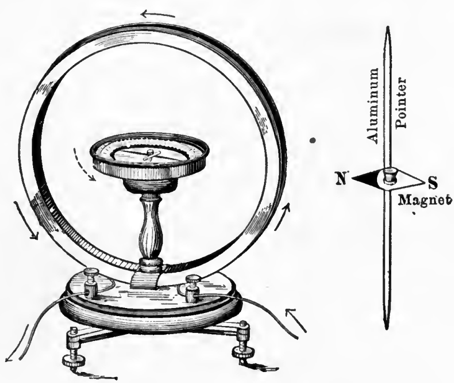


FIG. 137.

instruments are constructed for the especial purpose of determining the strength of currents. They are called *galvanometers*.

The *tangent galvanometer* (Fig. 137) usually consists of either few turns of thick wire or of many turns of thin wire, forming a coil eight inches or more in diameter. At the centre of this coil is placed a short, thick compass needle. To this needle, transversely to its length, is attached a very light aluminum pointer which indicates the distance through which the needle has turned tow-

ard the east or toward the west. This distance is read in degrees by use of a scale attached to the interior of the box containing the needle. The coil is placed in a north and south position and from the amount of deflection of the needle toward the east or toward the west, from the strength of the magnet, from the size of the wire used in

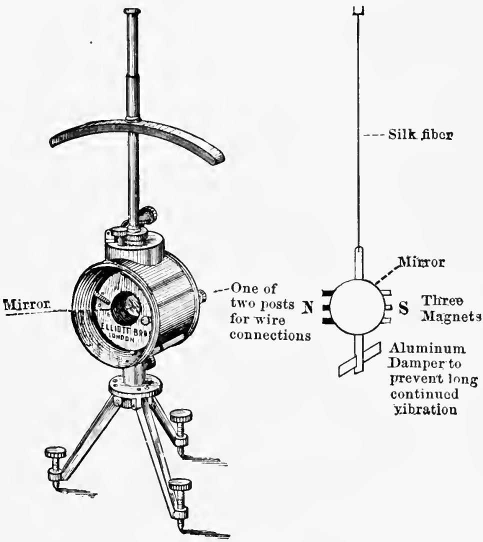


FIG. 138.

the coil, and the number of turns of the wire, the strength of the current may be determined.

Some galvanometers are made of a great many turns of wire. The magnetic needle is made very light, and is suspended from a single thread of silk so that even a very weak current will serve to deflect the needle. Such instruments may be called sensitive galvanometers. When a very light tiny mirror is fastened to the needle, any

motion of the needle may be detected by throwing light upon the mirror so that it will be reflected upon the wall or upon a screen. Any motion of the mirror causes the spot of light thrown upon the screen to move. An instrument of this type is called a *mirror galvanometer* (Fig. 138). A sensitive mirror galvanometer will be found extremely useful in demonstrating the presence of the weak currents produced during many of the following experiments.

305. An Electric Current Generated in a Wire while it is Cutting Lines of Magnetic Force.—It has already been shown that the direction of the strain in the ether may be represented by lines of force which leave the north-seeking end of the magnet, curve around through the air, and enter the south-seeking end. In the case of a permanent horseshoe magnet many of the lines of force pass in a nearly straight direction from the north-seeking pole of the magnet to the south-seeking pole (Fig. 121). If the magnet is so held that the north-seeking pole of the horseshoe magnet is directly above the south-seeking pole, the direction of strain may be represented by lines of force passing directly downward within the space between the poles. If then the magnet is turned so that the poles face northward (Fig. 139), and a horizontal wire is moved southward within the space between the poles, the direction of motion is transverse to the direction of strain in the ether. Since this direction of strain is represented by lines of force, it may also be said that the wire cuts the lines of force.

The result of the motion of the wire across the magnetic field is a change in the direction of the strain in the ether in the immediate vicinity of the wire. It has already been shown that a piece of soft iron placed in the

field of a magnet alters the direction of the strain. The mere placing of a piece of copper or other metal which is not magnetic does not sensibly alter the direction of the strain, but the *motion* of a copper wire *across* the magnetic field in some manner causes a change in the direction of this strain. The strain of the ether directly in front of the moving wire appears to be increased, and the direction of the strain at the side and the rear is altered in such a manner as to curve partly or entirely around the wire. This may be represented diagrammatically by drawing

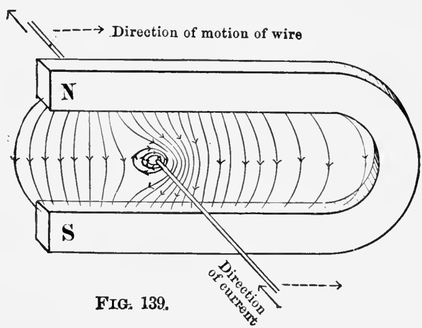


FIG. 139.

the lines of force so as to be crowded together on the side in front of the moving wire, with the lines of force nearest the wire entirely encircling it, leaving a somewhat smaller number of lines of force in the space immediately in the rear.

The circular strain around the wire is the combined result produced by the original strain of the ether from pole to pole, the increased strain in front of the moving wire, and the decreased strain behind.

It has been demonstrated that when a current passes through a wire the strain may be represented by lines of

force which pass around it in circles. From this it may be expected that the direct opposite is also true, so that when by any means the direction of strain in any magnetic field is so altered that it may be represented by lines of force passing around a wire, at least in the immediate vicinity of the wire as in the case of the present discussion, a current will tend to pass along the wire. If the wire is connected with a sufficiently sensitive mirror galvanometer, the existence of a current, when the wire is moved between the poles of the magnct, may be easily proved.

By reversing the thumb and finger rule, the direction of the current in the wire may be predicted. The direction of the strain in the ether in front of the moving wire always remains similar to the original direction of the strain in the magnetic field between the poles, even in the immediate vicinity of the wire where the lines of force are represented as encircling the wire. Therefore, grasp the wire with the right hand so that the finger tips touch that side of the wire toward which the wire is moving and at the same time point toward the south-seeking pole of the magnet. The extended thumb indicates the direction of the current in the wire.

In the preceding case a horizontal wire is supposed to be moving southward between the northward-facing poles of a horseshoe magnet, the north-seeking pole being above the south-seeking one. The application of the thumb and finger rule indicates that the current passes eastward through the wire. If the wire is moved northward while the poles remain in the same position, the current passes westward through the wire.

It is noted in a preceding paragraph that a magnetic

field encircles a wire only while a current is passing through the wire. The reverse is also true. In order that the magnetic field may produce a current in a wire its strain must be of such a character as to encircle the wire, so that it may be represented by lines of force passing around the wire. This is true only while the wire is kept in motion transversely to the original strain in the magnetic field of the magnet. Therefore the *current* in the wire ceases as soon as the *motion* of the wire ceases.

306. The Dynamo.—If a single loop of wire placed within the space between the poles is so rotated that the upper part of the wire loop moves southward at the same time that the lower part of the loop moves northward (Fig. 146, A and B), a current will pass eastward in the upper part of the loop at the same time that another current passes westward in the lower part. A brief examination will at once show that these currents in no manner interfere with each other, but that one current follows immediately behind the other around the loop.

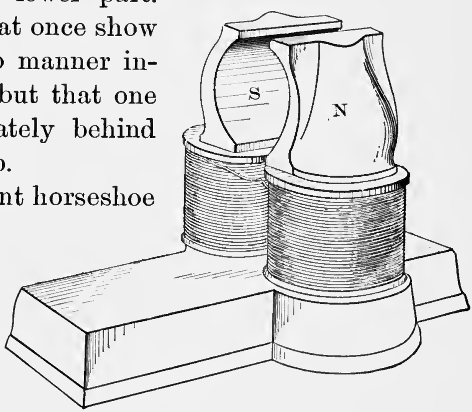


FIG. 140.

If instead of a permanent horseshoe magnet a very powerful electromagnet (Figs. 140, 141) is used, if instead of a single loop of wire a coil consisting of several hundred loops is employed (Figs. 141, 145), and if the coil is rotated more rapidly so as to complete a greater number of revolutions per second, the quantity of current pro-

duced by a single revolution of the coil is very much increased.

We have already learned that the strain of ether in a magnetic field is always very much increased by the presence of soft iron. If, therefore, the space between the poles within which the coil rotates is filled as much as possible with soft iron, the strength also of this field is very much increased, and the rotation of the coil within this stronger field produces a stronger current of electricity. In diagrammatic drawings this is represented by drawing a greater number of lines of force through the field when the space between the poles is largely occupied by soft iron. The rotation of the coil then causes the wire to cut a greater number of lines of force. In practice, the field within which the coil rotates is most effectively filled with soft iron by constructing a soft-iron core, with grooves left for the wire coils. The wire forming the coils is wrapped lengthwise in the grooves around this core. Those parts of the inner sides of the poles of the electromagnet which lie nearest to the coils are given a concave curvature so as to leave the air space between the coils and the poles of the magnet as small as possible (Fig. 140, N, S; Fig. 141, P).

The iron core with its coils is called the *armature* (Fig. 145, D). The electromagnet in whose field the armature revolves is called the *field magnet* (Fig. 140). When provision is made to permit the current to pass from the coils of the armature into other wires so that the current may be utilized, the combination is called a *dynamo* (Fig. 141).

307. The Current Produced in a Loop of Wire Rotated in the Field of a Horseshoe Magnet Fluctuates.—If attention be again confined to a single loop of wire revolving in

the field of a permanent horseshoe magnet (Fig. 139), it is seen that twice during every revolution, while the loop is horizontal, the wires move practically parallel to the direction of strain in the field. Under these circumstances, the ether is not strained more on one side of the wire than on

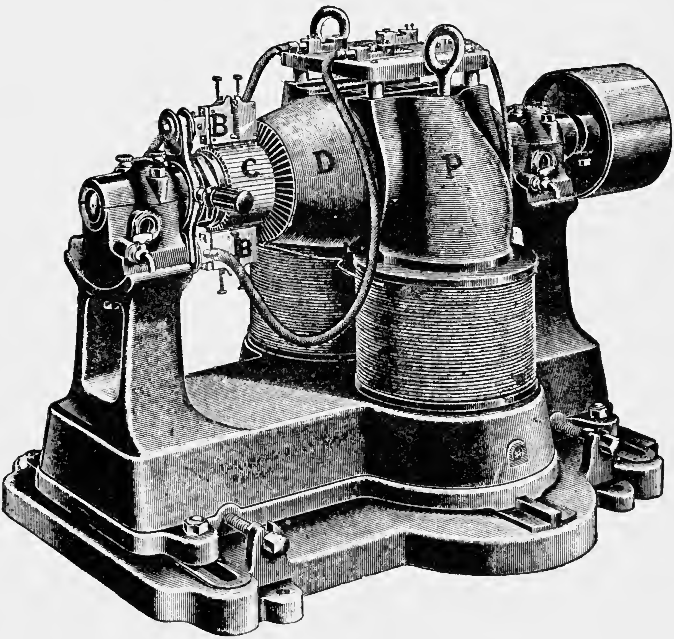


FIG. 141.

the other. In the diagrammatic representation of the field of the magnet it will be seen that during this part of the path of the wire of the loop the lines of force are not crowded more on one side of the wire than on the other. Therefore, during this part of its revolution no circular field is produced around the wire and the wire carries no

current. The maximum current, on the contrary, is produced when the wires of the loop are moving directly across the direction of strain of the magnetic field. This takes place while the rotating loop occupies a practically vertical position. Twice during every revolution, the current increases from zero to the maximum current and then falls again to zero. This

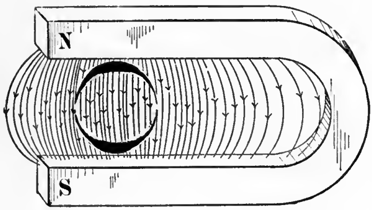


FIG. 142.

is represented diagrammatically in the figure (Fig. 142) by varying the thickness of the circular path followed by each wire of the rotating loop, from nothing, where the wire moves parallel to the lines of force, to the maximum thickness where it cuts most directly across the lines of force and thus

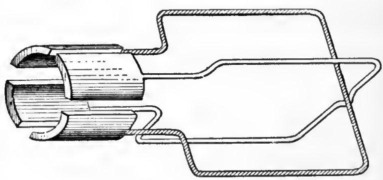


FIG. 143.

produces the strongest current. The irregularity of this current may be largely decreased by employing two loops at right angles with one another (Fig. 143), or three loops at angles of sixty degrees. In figure 144 there are four coils connected with each other in such a manner that the current can pass from coil to coil, D, and yet escape from the dynamo at the proper point (B). By this means there is always one part of one coil very near that part of its course

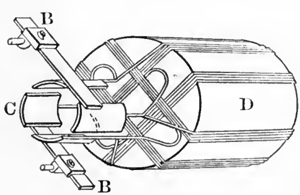


FIG. 144.

in which it produces its maximum current. This prevents the current from decreasing very much in strength at any time, and, therefore, makes it more steady. Some dynamos

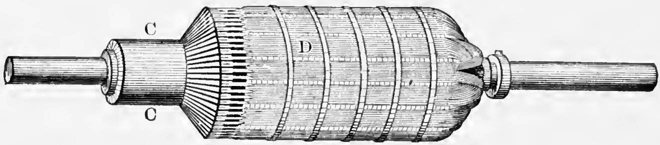


FIG. 145.

have armatures constructed upon this principle; they consist of a considerable number of coils of wire placed at different angles (Fig. 145, D).

308. The Current in the Coil Changes in Direction Twice during every Revolution.—If one-half of the wire loop is painted red and the other half green, it becomes evident

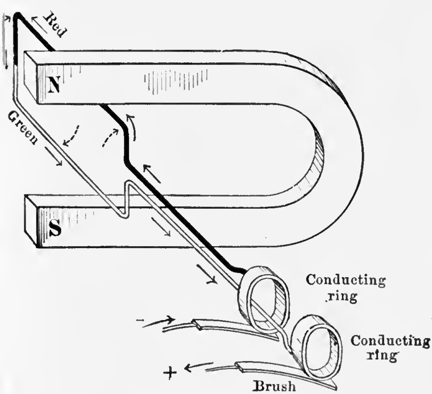


FIG. 146. A

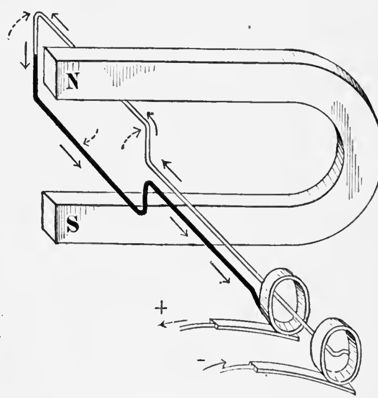


FIG. 146. B

that the red half of the wire carries an eastward going current while it passes from the extreme north position southward (Fig. 146, A). However, during the second

half of its revolution, while returning from the south to the north side, this half of the wire loop is traversed by a westward-flowing current. In the meantime, the current through the green wire has changed from a westward current to an eastward current (Fig. 146, B). The result is that the current in the coil changes in direction twice in the course of every revolution.

309. Alternating Currents.—A current continually varying in direction is said to be *alternating*. All currents produced by coils rotating in the fields of magnets are alternating, at least while the currents are still traversing the coil. If the ends of the wires of a rotating coil were fastened directly to wires leading to any instrument, it is evident that the wires would soon become twisted and broken. This is prevented in the following manner.

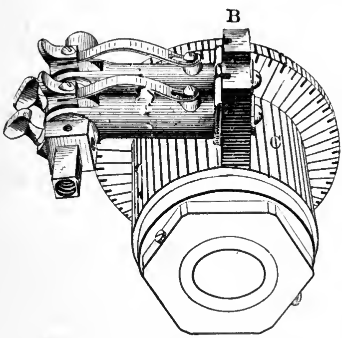


FIG. 147.

One end of the axle carrying the armature with its coil carries also two brass rings. One of the ends of the coil is fastened to one ring and the other end of the coil to the other ring (Fig. 146). These rings must be separated by some insulating material so that the current cannot pass directly from one ring to the other. As the armature rotates and the current changes in direction, the current tends to leave the dynamo first by one ring and then by the other. If two thin strips of metal press against these rings, the current will pass from the rings, first into one and then into the other of these strips. To these strips of metal, per-

manent wires leading to various electrical instruments may be fastened. In that case the current will enter alternately first one and then the other wire brush, producing an *alternating current* in the wire connected to the brush. The two rings may be called the *conducting rings*, and the thin strips of metal, the *brushes.* The thin strips of metal are often replaced by thick pieces of carbon (Fig. 147, B), and formerly were constructed of actual wire brushes. In figure 141, the carbon brushes are enclosed in brass holders, B, and only the lower ends of the carbons can be seen, where they are in contact with the commutator, C. A dynamo with conducting rings can produce only an alternating current.

310. An Alternating Current Changed into a Direct Current by Means of a Commutator.—If instead of two rings, a single ring is used, and if this ring is cut transversely into two equal halves, the ends of the coil connected to the half rings will send a current first into one and then into the other half ring. The two half rings are then known as a split-ring *commutator* (Fig. 148). In this case the brushes are placed on opposite sides of the commutator at such an angle that they come in contact with both halves of the commutator only at the moment at which the coil is producing practically no current. In other words, while the wires of the coil are moving parallel to the lines of force. If the coil be so rotated that the upper part of the coil always moves toward the south, then that half of the coil which is moving southward will always produce an eastward-moving current. By placing the brushes at the proper angle, it may be so arranged that the eastward-moving current, no matter by which half of the loop it is produced or by which half of the commutator it leaves, will always leave by the same brush,

while the returning current will always re-enter by the other brush. In other words, a split-ring commutator may be used to secure currents passing in one direction only.

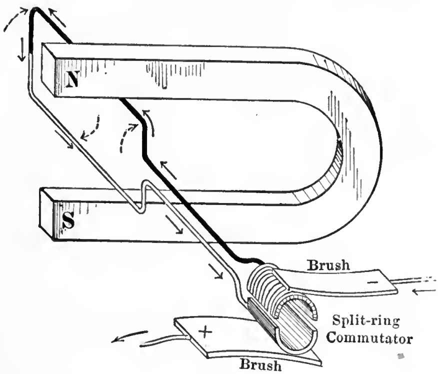


FIG. 148. A

By the use of a sufficient number of coils placed at various angles with each other (Fig. 145, D), in connection with an increased number of segments in the commutator (Figs. 141, 145, 147, C), a current may be secured which is not only constant in direction, but also fairly constant in strength. Dynamos constructed on this principle are called *direct current dynamos* (Fig. 141).

311. The Motor.—If a strong current of electricity be sent by way of the brushes into the single coil of wire found in a simple dynamo while the coil is in a horizontal position, in such a manner that the upper face of the coil becomes north-seeking, the north-seeking pole of the magnet being directly above,—the north-seeking magnetism of the coil will oppose the north-seeking magnetism

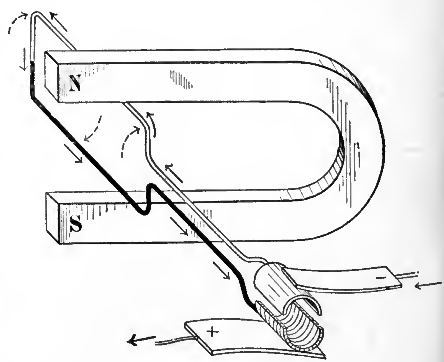


FIG. 148. B

of the magnet. The upper face of the coil and the north-seeking pole of the magnet, directly above, will mutually repel each other (Fig. 149), and, if the opposing magnetic effects are sufficiently strong, the coil will tend to move so that the north-seeking face of the coil will turn downward.

If a half-ring commutator is used, the current may be switched into the coil in such a manner that at the moment the north-seeking face of the coil is directly opposite the south-seeking face of the magnet, the direction of the current throughout the entire coil is changed. What was the north-seeking face of the coil now becomes the south-seeking face. The same conditions are therefore reproduced as at the beginning. The coil will therefore rotate once more and in the same direction. In other words, when a divided-ring commutator is used, the coil continues to revolve as long as it is supplied with a sufficiently strong current of electricity. The direct-current dynamo has become the direct-current *motor*.

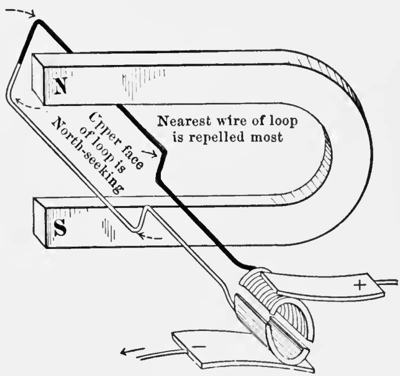


FIG. 149.

A motor is, therefore, the exact reverse of a dynamo. Power is necessary to revolve the coil of a dynamo and electricity results. Electricity is necessary to set in operation the coils of a motor and motion results.

312. Induction.—Any wire carrying a current is surrounded by a field within which magnetic effects are perceptible. These magnetic effects are strongest near the

wire and become gradually imperceptible as the distance from the wire becomes greater. Any increase in strength of the current passing through the wire is accompanied both by an increase of strain in the ether in every part of the magnetic field which already surrounds the wire and by an extension of the magnetic field to a greater distance from the wire. Conversely, any decrease in the strength of the current results in a decrease of both the strength and the extension of the magnetic field.

If around one coil of wire a second coil is wrapped in such a manner that the wires of the two coils at no point come in contact with each other (Fig. 151), it is evident that no current of electricity can pass directly from the first coil into the second. However, the magnetic field around the inner coil may extend to, and beyond the outer coil. Any increase in the strength of the current passing through the inner coil must result in an increase in the strain of the ether around the wire in each part of this coil. This increased strain is in part transmitted outward, affecting the magnetic field even beyond the outer coil. This spreading of the increased strain seems to be slightly checked on reaching the wire forming the outer coil. In consequence, the direction of strain of the ether in immediate contact with the wire forming the outer coil is altered to a circular strain and this results in a current through the wire.

The direction of the current in the wire of the outer coil due to the increase of current in the inner coil may be determined mechanically by the use of the line of force idea. Any increase in the strength of the current passing through a wire may be represented by an increase in the number of lines of force in every part of the field surrounding the wire and also by the spreading of these

lines of force so as to occupy a larger field. Conversely, any decrease in the strength of the current may be imagined to result in a shrinking of the lines of force accompanied by a diminution of their number and also by a decrease in the size of the field.

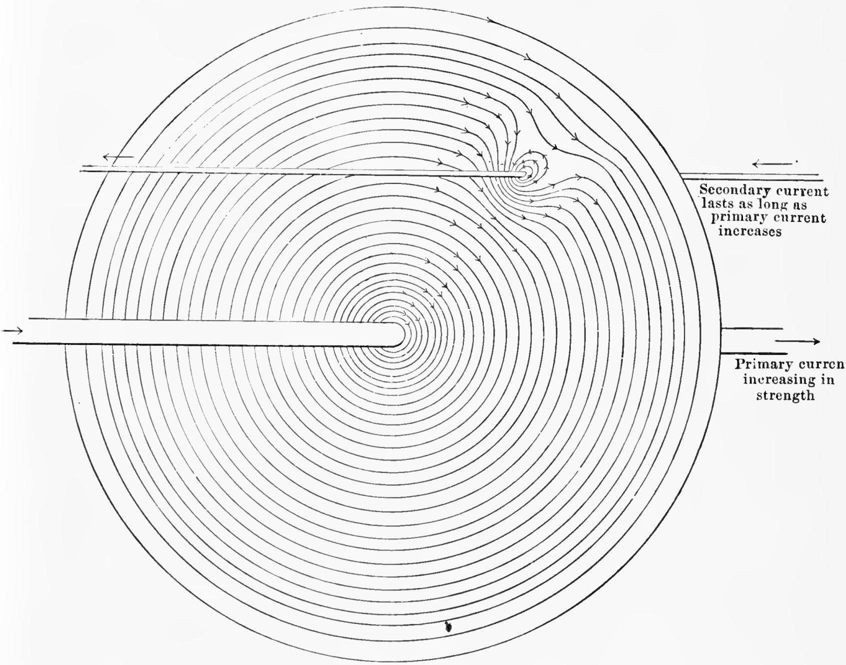


FIG. 150.

If in the vicinity of one wire carrying a current there is a second wire (Fig. 150), any increase in the strength of the current passing through the first wire must result in an increase in the number of lines of force passing around this wire. In consequence, the lines of force spread to a greater distance from the first wire and strike against the

second wire, which so far has not contained any current. But as soon as the lines of force of the first wire strike against the second wire, they begin to wrap around it and this results in the production of a current in the second wire, opposite in direction to the current present in the first wire.

By studying on which side of the wires of the outer coil the lines of force spreading from the inner coil are momentarily held in check, it is possible to determine in what direction the lines of force will pass around the wires of the outer coil, and what must be the direction

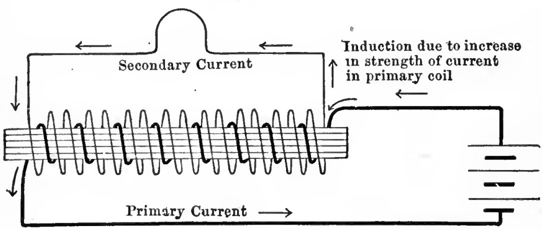


FIG. 151.

taken by the current in the outer coil. The current induced in the secondary coil is found always to be opposite in direction to that present in the primary coil (Fig. 151).

In one particular, the process is the exact reverse of that which is followed when a current is produced in a wire by moving it so as to cut directly across the lines of force between the poles of a magnet. In one case, the spreading of lines of force causes the lines of force to move toward and strike against the wire. In the other case the wire is moved toward and strikes against the lines of force. In both cases the lines of force wrap around the wire and a current results in the wire.

When the current in the inner coil decreases, the lines of force again contract. The result is a current in the opposite direction from that first produced in the outer coil. Increase and decrease of current in the inner coil therefore results in an alternation in the direction of the current in the outer coil.

The two coils of wire used in the manner here described may be called *induction coils.* Although two coils are always present, the combination is usually referred to in the singular number, as an induction coil. The name *Ruhmkorff coil* is frequently employed when, at one point in the outer coil, there is a break or spark gap, across which the secondary current must leap in order to complete the circuit. Induction coils are used with telephones. They are usually placed in the box below the transmitter. Ruhmkorff coils are used for wireless telegraphy (§ 322) and Roentgen rays (§ 323), although Holtz and Wimshurst induction machines may also be employed.

313. The Telephone.—In the case of telephones, the instrument into which you speak is called the *transmitter*, and that by means of which you hear is called the *receiver.* Two wires lead from the telephone instrument to the telephone station and from there pairs of wires lead off to other telephones in the same town or district. The connections between the wires from your telephone and those leading to any other house are made at the central station.

In the most recent systems in use the electric cells (storage cells) are all located at the central station. As soon as the receiver is lifted from its hook, the transmitter is in electrical connection with the central office, and there the connection is made with any other telephone.

314. The Transmitter.—The transmitter (Fig. 152) consists of a wooden box with an opening in front, behind which is a thin piece of iron, called a diaphragm, against which you talk. The sound waves produced by the voice strike against this diaphragm and push the central part forward. Between each sound wave the diaphragm flies back. When it is remembered that sounds of high pitch are caused by the production of many thousands of successive sound waves in a single second, it is almost inconceivable that even the thinnest metal plate should respond to all of these waves. Nevertheless this is actually the case, and every wave produced by the voice, or by any other sound-producing instrument, affects to some degree the motion of the diaphragm. A screw connects the centre of the diaphragm with the cover of a round brass box which, however, looks more like a round flat piece of brass as seen from the rear, on opening the door of the transmitter. The cover of this box consists of a thin sheet of mica to the centre of which is attached a thin brass disk. The screw already mentioned connects the diaphragm with the brass disk. As the diaphragm moves backward and forward the brass disk also moves in the same manner. To the inner side of the brass disk and to

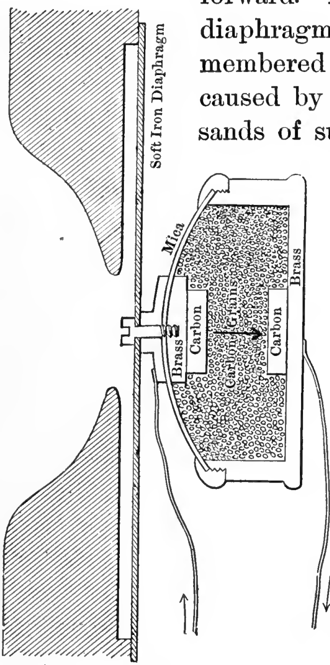


FIG. 152.

the base of the box directly opposite are fastened two round and highly polished carbon disks. Between these disks the box is filled with minute carbon grains.

The current comes from the battery at the central telephone station to the receiver and passes by a thin connecting wire to the brass disk on the cover of the box. Thence it passes through the carbon disk attached to the brass disk, through the carbon grains to the carbon disk at the base of the box, and finally through the brass box itself by another thin wire to the wire returning to the station.

Whenever a sound wave throws the diaphragm forward, the cover of the box presses the carbon grains together so effectively as to cause them to transmit electricity better than when the diaphragm moves back and the carbon grains are slightly less crowded. Every motion of the diaphragm therefore causes a corresponding change in the strength of the current passing through the transmitter, and therefore through the wires leading to the central office and thence to the other telephone. It is difficult to conceive that the slight variations in compression of the carbon grains should cause such distinct variations in the strength of the current that the hundreds or thousands of the sound waves produced by the voice in the course of a single second, result in a corresponding number of variations in the current of electricity passing through the transmitter. This, however, is the case.

315. The Receiver.—The receiver (Fig. 153) consists of a long, round bar magnet with the north-seeking end almost touching the centre of the metal diaphragm. The cover of the receiver may be easily unscrewed and the soft iron diaphragm removed. There is then seen a small spool surrounding the north-seeking end of a permanent

bar magnet (Fig. 154). The spool is wrapped with many turns of very thin wire covered with silk. The ends of this wire pass lengthwise through the receiver, from the spool, along the magnet, to the inner ends of the binding posts at the rear of the instrument.

When a current is sent through the coil of wire on the spool in one direction, the end of the coil facing in the same direction as the north-seeking pole of the permanent magnet becomes also north-seeking (Fig. 154, A). The magnetic effect produced by both the permanent magnet and by the coil is now greater than that produced a moment before by the magnet alone. The thin soft iron diaphragm is therefore attracted more strongly, and is drawn slightly nearer to the end of the magnet. When, however, the current is sent in an opposite direction through the wire, the end of the coil facing in the same direction as the north-seeking pole of the magnet becomes south-seeking (Fig. 154, B). The south-seeking magnetism of the coil slightly counteracts the north-seeking magnetism of the bar magnet. The magnetic effect produced by both magnet and coil is then less than the effect usually produced by the magnet alone. The

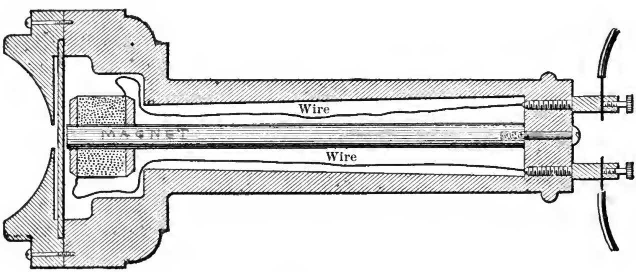


FIG. 153.

diaphragm is attracted even less than when no current in any direction is passing through the coil. In consequence the diaphragm springs back to a position slightly more distant from the end of the permanent magnet than when no current is passing. Any change in the direction of the current through the coil results in a variation in the degree of attraction of the diaphragm, and this causes the diaphragm to move backward and forward.

316. The Use of Induction Coils in Telephone Circuits.— It has been shown (§ 312) that any variation in the

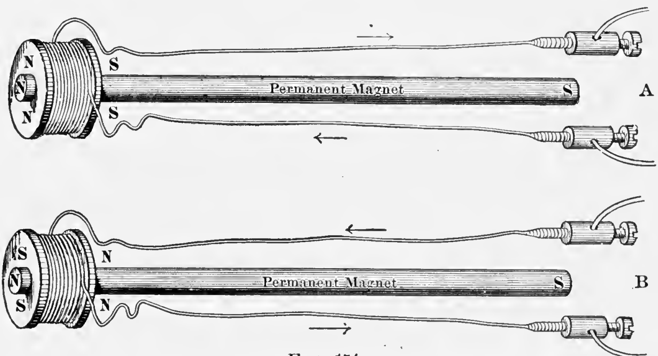


FIG. 154.

strength of a current of electricity passing through a coil of wire surrounded by another coil must result in a current passing through the outer coil. Any increase in the strength of the current in the inner coil produces a current in the opposite direction in the outer coil, while any decrease in the current in the inner coil results in a current in the same direction in the outer coil. It has also been shown (§ 314) that the variable pressure produced by a succession of sound waves striking the diaphragm of a telephone transmitter is able to produce a variable current through the transmitter.

If, therefore, the variable current passing through the transmitter, during the use of a telephone, be sent through the inner one of two induction coils (Fig. 151), secondary currents of electricity will be produced in the coil immediately surrounding the first. These secondary currents will vary in strength and direction with the variations in the strength and direction of the current in the first coil. If the inner coil consists of comparatively few turns and the outer coil is formed by a much greater number of turns of wire, the current produced in the outer coil will move with greater violence along a greater length of wire than could be passed over by the current in the inner coil.

By connecting the two ends of the wire in the outer coil with the two binding posts at the rear of the receiver, the variations in the strength and direction of the current in the outer coil may be used to produce currents varying in strength and direction in the coil wrapped around the end of the permanent magnet in the receiver. This will result in forward and backward motions in the diaphragm of the receiver. By properly connecting the ends of the wire of the outer coil with those of the receiver, every motion of the diaphragm in the transmitter will be imitated by the diaphragm in the receiver.

This would be true if the wires leading from the transmitter were connected directly with the wires of the coil around the spool in the receiver. However, when induction coils are employed, which possess a much greater number of turns of wire in the outer coil than in the inner one, the force with which the current produced in the outer coil tends to move is much greater than the force shown by the current in the inner coil. Hence the secondary current produced in the outer coil speeds on from the outer coil to the receiver with much greater force

than the current which comes from the transmitter to the inner coil of the induction coils. The secondary current produced in the outer coil, therefore, can overcome a much greater resistance (§ 318) and pass through a much greater length of wire than that traversing the inner coil. The use of the induction coils is therefore to secure a current which will tend to move through the street wires to the receiver with much greater force than the current coming directly from the transmitter, and at the same time to secure a current whose variations in strength and direction are a precise duplicate of those coming from the transmitter.

317. Action of the Telephone.—Each sound wave caused by the voice pushes the diaphragm of the transmitter forward, and this produces a better contact between the carbon particles. The result is an increased flow of electricity through the first coil. During this increase of current, a momentary current passes in the opposite direction in the second coil, and by proper connections with the spool in the receiver, the diaphragm in the receiver may likewise be caused to move forward. During the interval between two sound waves, the diaphragm of the transmitter flies back, and in consequence the carbon particles of the transmitter are in looser contact with one another and a smaller current flows on to the first coil. The decrease of current in the first coil is accompanied by a momentary current in the second coil having the same direction as that in the first coil. The direction of the current in the spool of the receiver, is in consequence reversed. The diaphragm of the receiver, therefore, moves in the opposite direction. In this simple manner the diaphragm of the receiver is caused to imitate all the motions of the diaphragm of the transmitter.

The diaphragm of the transmitter is set in motion by

the waves of the voice. The motions of the diaphragm of the receiver, however, set the air in motion, and these motions reproduce the original sound.

318. Conductors.—The ability of different substances to conduct electricity varies considerably. Metals are the best conductors, but different metals vary considerably in conductivity. Silver and copper are the best conductors. Soft iron and platinum conduct only one-sixth as well. German silver conducts about one-twelfth as well. As compared with this carbon is a poor conductor. The power to conduct electricity varies not only with the substance, but also with the area of cross section of the wire, fibre, or rod which conducts the electricity. On this account a thick rod of carbon may serve to conduct electricity much better than a thin copper wire.

The electricity may pass also more readily through a short piece of wire than through a longer one. Electricity may pass most readily through a short thick piece of wire constructed of the best conducting material, silver or copper. It may pass far less readily through a long thin piece of an only moderately good conductor, such as German silver. Any body which does not readily permit the flow of electricity through it, is said to offer resistance to the flow of electricity. It is often desirable not to have too great a flow of electricity through certain machines when they are first started. This may be managed by causing the current of electricity at first to flow through a considerable length of some poor conductor of electricity. After the machine has once started in operation, the current is caused to flow through a much shorter length of the poor conductor, thus causing the larger part of the current to flow through the machine. Boxes with coils arranged for the purpose of controlling the

amount of flow of electricity are often called *resistance boxes.* The resistance boxes at the front end of electric street cars control the quantity of current admitted to the motor beneath the car, and are hence called *controllers*, Resistance coils are also used in connection with stereopticons for the purpose of regulating the flow of electricity through the lamp.

319. The Incandescent Lamp.—Anything which offers resistance to the flow of electricity becomes heated in consequence. The same flow of electricity through the same

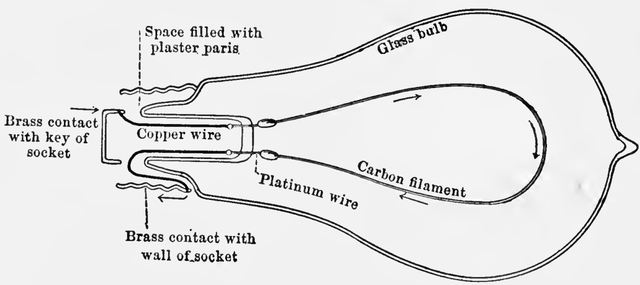


FIG. 155.

length and thickness of copper, platinum, and carbon will heat the platinum more than the copper, and the carbon far more than either of the other two. This may be seen in the case of an ordinary incandescent electric light (Fig. 155). In this case the carbon filament within the lamp becomes very much more strongly heated than the very short pieces of platinum which connect the ends of the carbon filament within the lamp to the copper wires at its base. The result is that the carbon filament becomes white hot, while the copper and platinum wires become heated, but not sufficiently to produce light.

320. The Arc Light.—Fasten two pointed pieces of carbon to the wires leading from a powerful voltaic battery or from a dynamo in such a manner that, when the carbons are allowed to touch, the circuit is closed. Bring the points of the carbons in contact for a few seconds and then slowly separate them. The points of the carbons become heated to incandescence, and a luminous arc is seen to extend between them.

When the carbons are permitted to touch, a current passes through them. As they are separated, the current leaps across the small gap and volatilizes some of the carbon. This carbon vapor, being a partial conductor, permits the current to flow across the gap, provided the gap is not too wide. The ends of the carbons are more brilliant than the vapor between them. The tip of the carbon connected with the wire from the positive pole of a battery or dynamo is slowly consumed so that it possesses a cup-shaped cavity called the *crater* (Fig. 156). It is this crater which is the hottest and most luminous part of the light.

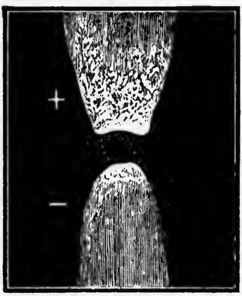


Fig. 156.

Since the carbons slowly waste away, it is necessary to keep moving them toward each other in order that the distance between them may remain practically uniform. In most arc lights in use this is accomplished by an automatic arrangement controlled by an electromagnet.

321. The Production of Electric Waves by Induction Coils.—In one of the instruments utilizing induction coils, called the Ruhmkorff coil (Fig. 157), the current sent through the inner coil is automatically broken and re-established

many times in the course of each second by a specially devised mechanism. The violent fluctuations in the strength of the current passing through the inner coil, produced in this manner, result in alternating currents in a second coil of wire, wrapped around the first. The number of turns of wire in the outer coil is much greater than that used for the inner coil. In large instruments the outer coil is made of very thin wire and many thousands of turns of wire are present. Hence the force with

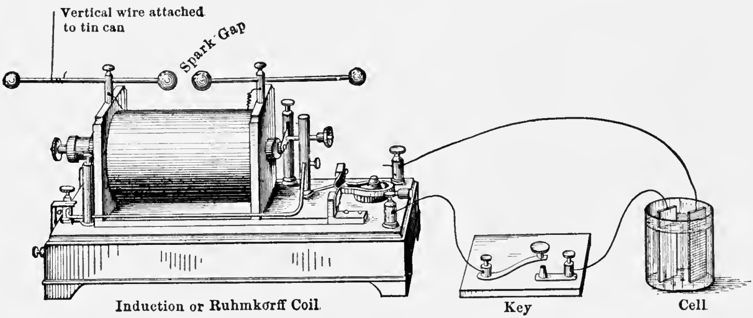


FIG. 157.

which electricity is urged to move onward is so much greater than that present in the inner coil that the electricity can jump across a considerable gap through the air if the circuit belonging to the outer coil is anywhere broken.

Since the current of electricity in the outer coil alternates rapidly in direction, in consequence of the rapid automatic breaking of the circuit belonging to the inner coil, the passage of electricity through the air or spark gap also alternates in direction. The result of these alternating discharges of electricity through the air is the

production of a succession of sparks accompanied by oscillations or waves in the ether. The production of these waves in the ether appears to be much facilitated by attaching a long vertical wire to some part of the circuit belonging to the outer coil.

A closer examination of the discharges of electricity through the air-gap has shown that the passage of electricity across the air-gap is not accomplished by a single discharge on each change in direction of the current, but that each apparent single discharge consists in reality of a very rapid succession of discharges alternating in direction. The setting up of waves in the ether is therefore a somewhat complicated process.

322. Wireless Telegraphy.—The oscillations or waves in the ether produced by a large Ruhmkorff coil, to which a vertical wire has been attached, may be used for purposes of wireless telegraphy. At the sending station an ordinary telegraph key is inserted in the circuit including the inner coil of the Ruhmkorff coil and the electric cells (Fig. 157). By this means, the length of time during which electricity flows through the inner coil may be controlled as in ordinary telegraph instruments. The production of currents of electricity in the outer coil takes place only when the telegraph key is depressed, and ceases the moment the key is permitted to spring back. The production of waves in the ether is due to an alternating discharge of the electric currents in the outer coil across the spark-gap.

At the receiving station are two small but complete circuits (Fig. 158). In the first circuit are several gravity cells, which send a current through the electromagnet of a relay and through a glass tube containing nickel filings held in place loosely by metal (silver) disks. This tube

is called the *coherer*. Loose nickel filings under ordinary circumstances offer a considerable resistance to the flow of electricity, but when struck by electric waves or oscillations they, in some mysterious manner, become good conductors of electricity. Therefore, a good current of

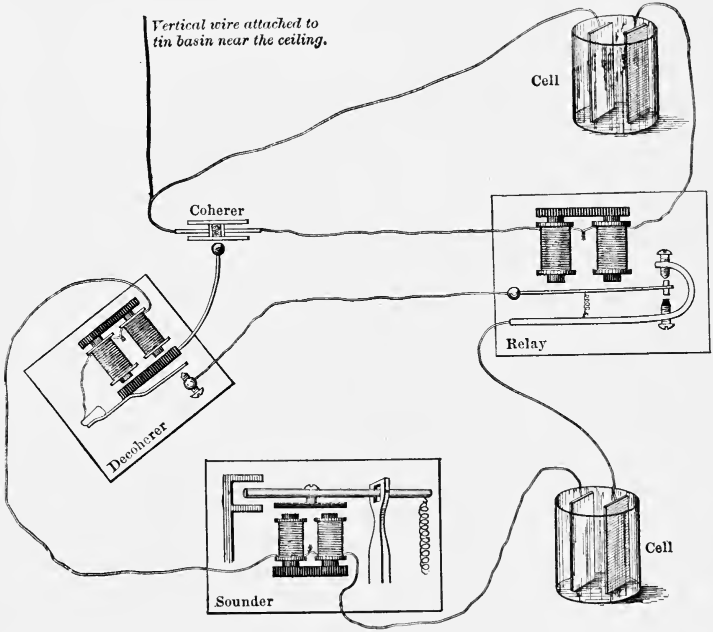


FIG. 158.

electricity passes through the coherer at the receiving station as long as the key at the sending station remains depressed, and during this time the electromagnet of the relay attracts its armature. As soon as the key at the sending station is permitted to spring back, the production of electric waves or oscillations ceases, the nickel fil-

ings lose their conductivity, and the armature of the relay is permitted to be drawn back.

The armature of the relay serves as a key to a second circuit at the receiving station. This circuit includes a sounder, as in ordinary telegraphy. It also includes an electromagnet whose armature is supplied with a tapper. An electric bell may be fitted up for this purpose. This tapper continues to strike against the coherer as long as the current flows through the circuit. By this means the nickel filings in the coherer are shaken up and lose their conductivity much more completely than by the mere cessation of electric waves in the ether. On this account the electromagnet with its tapper is called a *decoherer*. As long as electric waves arrive from the Ruhmkorff coil, the nickel filings are caused to cohere the instant they are decohered by the tapper. Practically this results in uninterrupted cohering. But as soon as the waves cease to arrive, the hand having been taken off the key at the sending station, the last stroke of the tapper leaves the nickel filings too loose to convey a good current. Hence all electric action ceases also at the receiving station.

323. Roentgen Rays.—The ends of the wires forming the outer coil of a Ruhmkorff coil (Fig. 159) may be inserted at the extremities of a large tube and the points of entry closed air tight. The discharge of electricity will then take place through the air enclosed within the tube. If an opening exists in one side of the tube through which the air may be pumped out, the effect of decrease of density of air upon the character of the discharge of electricity through the air-gap may be studied.

Dry air of ordinary density offers a considerable resistance to the passage of electricity, and the discharge of elec-

tricity through the air is by a bright, clearly defined path. As the density of the air becomes less the discharges of electricity through the air become more frequent and the light less intense. Moreover, the path followed by the electricity while passing through the air is less distinct, and the air surrounding it begins to glow with a bluish or purple light. As the density of the air becomes less, the path taken by the electricity gradually becomes invisible, while

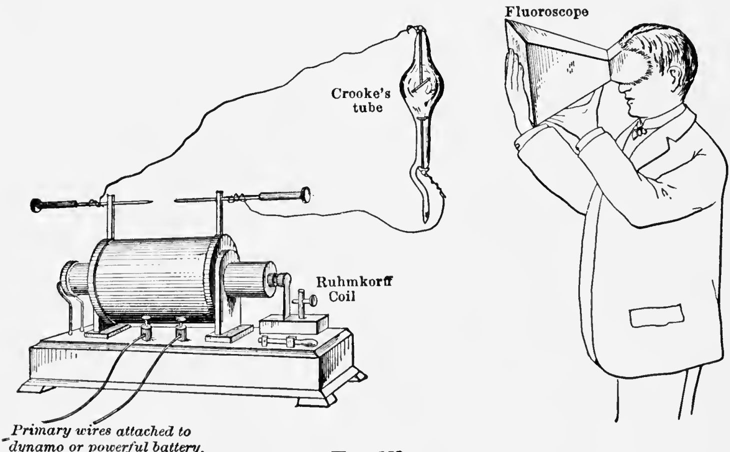


FIG. 159.

the purple glow of light extends until it fills the entire tube. After about $\frac{149}{150}$ of the air has been withdrawn from the tube, the glow of light due to the passage of electricity takes the form of a succession of regions of stronger light alternating with regions of comparative darkness. Finally when nearly all the air has been removed the discharge of electricity through the tube becomes nearly invisible.

The passage of the current through the tube is now accompanied by the production of waves at the end of one

of the wires entering the tube, the end by which the electricity is supposed to leave the tube, the *cathode* end. These waves have the power of passing through many substances ordinarily called opaque, such as flesh, leather, most kinds of clothing, paper, wood, ebonite, and many other substances. They pass with much less readiness through most metals, and through thick glass. Since these rays are capable of affecting the chemicals on a photographic plate, it is possible by their means to take photographs of coin enclosed in leather pocket-books, or of bullets lodged in the flesh, or of broken bones in the case of a broken arm or leg. These rays have also the power of making certain chemicals, such as calcium tungstate, glow in the dark. By holding the hand in a dark room between the source of the rays and a sheet of cardboard covered with calcium tungstate, the bones may be seen as dark shadows within a slightly darkened area due to the passage of the rays through the flesh (Fig. 160). Tubes especially constructed for the study of discharges of electricity through nearly perfect vacua are called Crooke's tubes. The sheet of cardboard covered with calcium tungstate is known as a fluorescent screen. It is usually placed at one end of a box whose opposite end fits closely against the face. This leaves the interior of the box dark, and makes it unnecessary to perform the experiment in a dark room. The box with its fluorescent screen at the end is called a *fluoroscope*. The rays here described are called either X-rays or Roentgen rays.

324. Electricity and Magnetism Are Phenomena of the Ether.—It will be noticed from the preceding paragraph that electrical phenomena do not cease when the air has all been practically removed from a Crooke's tube. From this it may be concluded that electrical phenomena, al-

though profoundly affected by the presence of other substances, are after all mainly phenomena of the ether. The

FIG. 160.

passage of electrical oscillations through the air suggest the same conclusion, since the passage of these oscillations in wireless telegraphy not only vastly exceeds in speed the most rapid transmission of vibrations of sound through the air, but equals in speed the transmission of light through space. Since magnetic phenomena always accompany the passage of electricity, magnetism must also be a phenomenon of the ether. In what way various substances produce the various known modifications of these phenomena of the ether is at present unknown.

Electricity gives rise to so many curious phenomena and permits so many interesting applications to useful ends that it is impossible to describe more than a small part in an elementary book. The choice of the material to be selected under these circumstances must be determined therefore chiefly by its usefulness as an introduction to the subject. Since this is a matter of judgment, each writer or teacher is liable to make a different selection. The pupil will find an interesting continuation of this subject in Sylvanus Thompson's Elementary Lessons in Electricity and Magnetism.

CHAPTER VIII

MECHANICS

325. Gravitation.—It requires considerable exertion merely to hold a cannon-ball, even if no effort is made to carry it for any distance. The ball acts as if something were forcing it downward—and yet nothing touches the ball except the hand and the air. It cannot be the air which is urging the ball downward. The air, rather, resists the effort of the ball; for have we not learned that the upward pressure of the air on the lower surface of the ball must be greater than the downward pressure of the air on the top of the ball (§§ 51, 52)? And, does this not leave an excess of upward acting force to counteract, to a slight extent, the effort of the ball to move downward? And, if the ball is allowed to drop, does not the friction of the air through which the ball must drop retard the motion of the ball slightly?

No cause for the motion can be detected. There is no visible connection between the ball and the earth. As far as can be seen there is nothing either pushing or pulling the ball. The only fact of which we are absolutely certain is that the ball seems urged toward the earth by a certain force which we call gravitation. The strength of this force can be measured by fastening the ball to a spring balance by means of a string.

326. Directions in Which Gravitation Acts on the Surface of the Earth.—The direction in which the force acts is

shown by the direction of the string. This direction is straight downward. No matter to what portion of the surface of the earth the ball be taken, the string from which it is suspended will always point downward. Does this mean that the ball always tries to move in the same direction? We who have studied geography know that it means anything but that; for the earth is round, and down at one point of the surface of the earth is an entirely different direction from down at any other point.

In fact down practically means toward the centre of the earth. No matter upon what portion of the earth the ball may be, it will try to move toward the centre of the earth.

Even at the same part of the surface of the earth, down does not mean in the same direction at all times; for the earth turns round on its axis, and the direction of a line pointing toward the centre of the earth changes at every instant. A man at the equator may look up at noon and again at midnight. He has looked up in both cases and yet he has looked in exactly opposite directions. Why do not those people fall off the earth who live on the side opposite us? Because something forces them toward the centre of the earth just as we are forced toward the centre of the earth.

327. The Force of Gravitation Due to the Earth is Less at Points More Distant from the Centre of the Earth.—The force with which a body is urged toward the earth is not the same in all localities. It is less at the tops of high mountains than at the level of the sea. The greater the distance from the centre of the earth, the weaker is this force. This fact can be determined experimentally with wonderful exactness, but the experiments involve a very exact knowledge of the laws of the pendulum (§§ 337–342).

When we move away to points more distant from the centre of the earth, the force with which a body is urged toward the earth decreases much more rapidly than the distance of the body from the earth increases. In fact, it has been found that *the strength of the force diminishes in proportion as the square of the distance of the body from the centre of the earth increases.*

328. The Earth Attracts the Atmosphere and the Moon.—Notwithstanding this rapid diminution of force, the air from a distance of fully 100 miles is urged toward the earth, so that, as the earth moves through space, it carries the air with it. The atmosphere is not the only material which follows the earth on its journey through space. No matter in what direction the earth may be travelling in its path around the sun, it is always accompanied by the moon. Although the moon is 240,000 miles away, it is continually being urged toward the earth. If it were not for the fact that the moon has a motion of its own which tends to carry it away from the earth, the moon would not only keep near the earth, but would long ago have come crashing into the earth.

We do not know whether the force urging the moon and other objects toward the earth is in the nature of a push or a pull. It is usually assumed, however, that it is a pull and the earth is said to attract the moon and other objects.

329. The Earth is Attracted by the Sun.—The earth is not the only body which attracts other objects. It moves around the sun at an enormous rate of speed. If something were not urging the earth toward the sun, it would fly off and leave the sun just as a stone fastened to a string and whirled rapidly around through the air will start off in a straight line the instant the string breaks.

The sun seems to attract the earth, just as the earth attracts the moon. In the same manner the sun attracts the planet Jupiter, and Jupiter attracts five moons.

330. Every Object Attracts Every Other Object.—Nor is the power of attraction confined to the heavenly bodies. Every object attracts every other object. Very interesting experiments have been devised in order to prove this. In one of these experiments, it may be shown that two thin glass globes filled with mercury attract each other in a distinctly perceptible manner.

If every object attracts every other object, not only does the earth attract the iron ball, but the ball must also attract the earth. From this follows another and more striking conclusion, that not only does the ball fall toward the earth, but the earth also falls toward the ball. This is actually the case. But, in order to understand why the motion of the earth toward the ball is not perceptible, it is necessary to understand what is meant by quantity of motion.

331. Velocity, Mass, and Momentum.—A body moving from one position to another occupies time. The amount of time consumed by a body in passing over a given distance depends upon its rate of motion, or how fast the body is moving. This rate of motion of a body is called its *velocity*. In determining the velocity of a moving body not only must the distance passed over be considered, but also the time which is consumed. A body which moves a distance of 5 feet in one second is said to have a velocity of 5 feet per second.

The quantity of motion of a body is called *momentum*. Common experience has taught us that, if two bodies, one heavy and the other light, are moving with equal velocities, it is much more difficult to stop the heavy

body than it is to stop the light one. In this case the body having the greater amount of material, or *mass*, has the greater quantity of motion. If one body is moving faster than another body of equal mass, the more rapidly moving one is the harder to stop. The momentum of a moving body depends, therefore, upon both its mass and its velocity.

If two bodies have equal velocities, but the mass of one is four times the mass of the other, the quantity of motion of the greater is four times that of the lesser body. If one of two bodies of equal mass is moving four times as fast as the other, its quantity of motion is four times that of the more slowly moving body. A body which has both four times the mass and four times the velocity, as compared with another body, has 4×4 or 16 times the quantity of motion possessed by the other body. Therefore, the quantity of motion, or momentum, of two bodies may be compared by comparing the product of the mass and the velocity of one body with the product of the mass and the velocity of the other body. If a ball weighing 4 pounds moves 4 feet in one second, it has the same momentum as a body weighing 1 pound moving 16 feet in 1 second. This does not mean that both balls would do the same amount of injury, if they should strike another object, but that their momentum is the same.

332. Both Bodies Which Attract Each Other Will Fall toward Each Other if Free to Move.—If the earth falls toward the ball, while the ball is falling toward the earth, the momentum of both the earth and the ball is the same. But, in this case, since the mass of the earth is enormously greater than the mass of the ball, the distance moved by the earth in one minute must be entirely imperceptible, notwithstanding the fact that

the ball may have moved thousands of feet toward the earth.

It is scarcely likely that anyone will ever be able to prove by means of direct observations, that the earth falls toward the ball. But it has been proved by astronomers that the earth and moon fall toward each other, and that the quantity of motion, when the earth falls toward the moon, is the same as the quantity of motion when the moon falls toward the earth. Why this does not cause the earth and moon to rush toward each other and to break each other up into fragments, cannot be understood, until the character and causes of curvilinear motion are known (§ 345).

333. Uniform Motion.—A body which moves over equal distances in successive equal intervals of time is said to have *uniform motion.* For instance, if a body continues to move over a distance of 5 feet each second, it neither increases nor decreases in velocity and its motion is uniform. A body which moves a distance of 5 feet each second will in 6 seconds move $5 \times 6 = 30$ feet. Hence, to find the distance passed over when the uniform velocity and the time are given, multiply the velocity by the time.

Calling the velocity v, and the time t, and the entire distance passed over s, the above rule can be stated in the language of mathematics by $s = vt$. Such a statement is called a *formula.* After the formula for a given class of problems has once been secured, there is no longer any need of going through the long reasoning process required either in obtaining the formula, or in working out each problem independently. All that is required is to substitute for the letters in the formula their respective values as given in the problem. This results in an

equation which can be readily solved. If it is required to find the distance passed over in 10 seconds by a body having a uniform velocity of 8 feet per second, substitute, in the formula $s = vt$, 8 for v, and 10 for t, and the result is $s = 8 \times 10$. Whence $s = 80$ feet.

It is often convenient to have the formula so written that the quantity whose value is to be found is placed by itself on one side of the sign of equality. If instead of the above problem, it were given that a body moved 80 feet in 10 seconds, to find the time, the 80 would be substituted for s in $s = vt$ and 10 for t, which would give the result $80 = v \times 10$, or $80 = 10v$; whence $v = 8$. By algebraic processes $s = vt$ can be readily changed into $v = \frac{s}{t}$, and $t = \frac{s}{v}$. In the problem just given it would be more convenient to use the formula in the form of $t = \frac{s}{v}$ than in the original form of $s = vt$.

334. Uniformly Accelerated Motion. — Anyone who watches a train starting from a station can observe that the velocity of the train is constantly increasing until full speed is attained, when its motion is practically uniform. On the contrary, when a train approaches a station, its speed becomes slower and slower until the train stops. If it be desired to determine the velocity of the train at any point while its speed is either increasing or decreasing, it will be necessary to determine what distance the train would pass over in a second, minute, or hour, with a uniform velocity, equal to the velocity of the train at the point in question. If a ball rolling down hill has at the end of the third second a velocity of 20 feet per second, it will move during the fourth second a distance of 20 feet, provided its velocity does not change after the third second.

A force, acting upon a body which is free to move, produces motion in that body. As long as the force continues to act in the same direction, the body will continue to gain in velocity. The rate of gain in velocity is called *acceleration*. If the force is uniform, the acceleration will be uniform. If a body started from rest and had a velocity of 5 feet per second at the end of the first second, a velocity of 10 feet per second at the end of the second second, and a velocity of 15 feet per second at the end of the third second, it can be seen that the rate of gain in velocity per second is 5 feet per second. If a body starting from rest has a uniform acceleration for each second of 5 feet per second, it will have at the end of 10 seconds a final velocity of $10 \times 5 = 50$ feet per second. Hence to find the final velocity for a body starting from rest, when the time and acceleration are given, multiply the acceleration by the time.

Calling the final velocity v, the acceleration a, and the number of seconds t, we can express the above rule by the formula $v = at$. From this formula can be derived by algebraic processes $a = \frac{v}{t}$, and $t = \frac{v}{a}$.

If a body start from rest with a uniform acceleration of 8 feet per second, it will have a velocity at the end of 10 seconds of $10 \times 8 = 80$ feet per second. Since the body started from rest, its initial velocity is 0, and, since its final velocity is 80 feet per second, its average velocity for the 10 seconds is $\frac{1}{2}$ of $80 = 40$ feet per second. Then the distance passed over is $10 \times 40 = 400$ feet.

Calling the acceleration a, and the number of seconds t, the final velocity is at. The average velocity then is $\frac{1}{2}$ of $at = \frac{at}{2}$. Multiplying the average velocity by the time we have $\frac{at}{2} \times t = \frac{at^2}{2}$ or $\frac{1}{2}\,at^2$. Hence the distance (s)

passed over may be represented by the formula $s = \frac{1}{2}at^2$. That is, the distance passed over by a body starting from rest with uniform acceleration is equal to one-half the acceleration multiplied by the square of the time.

By algebraic processes the formula $s = \frac{1}{2}at^2$ can be changed into the following forms:

$$a = \frac{2s}{t^2},\ t = \sqrt{\frac{2s}{a}},\ \text{and}\ s = \frac{v^2}{2a}.$$

335. Falling Bodies.—It has been ascertained by experiment that, if a body is free to fall, it will acquire during each second of its fall an increase in velocity of 32 feet per second (32.16 ft. at New York City). This is true of all bodies, whether large or small, light or heavy, provided there is nothing to resist their fall. The reason a piece of paper does not fall as fast as a lead bullet, when the two are dropped simultaneously from the top of a tower, is because in proportion to its weight the paper meets with more resistance from the air than does the bullet. If, however, the two had been dropped in a vacuum instead of in the air, they would both have struck the ground at the same time (Fig. 161).

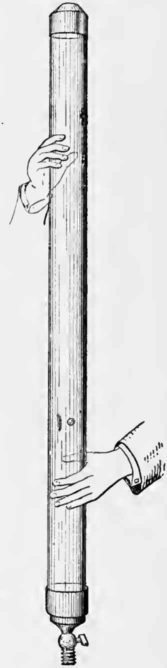


FIG. 161.

It is true that the farther we get above the earth's surface, the less is the force of gravity, but, unless the body under consideration is falling from a very great height, the force of attraction at any locality may without producing any appreciable error be considered constant. Since this force is constant, the acceleration due to gravity is uniform and the laws of falling bodies are the same as those of uniformly accelerated

motion. Instead, however, of representing the acceleration due to gravity by a, it is customary to represent it by g, the initial letter of the word gravity. We may, therefore, re-write the formulas already secured for bodies having uniformly accelerated motion, so as to make them apply to falling bodies. Substituting g for a in the formulas for bodies having uniformly accelerated motion (§ 334), we have the formulas for falling bodies, $v = gt$, $s = \frac{1}{2} gt^2$, $g = \frac{2s}{t^2}$, $t = \sqrt{\frac{2s}{g}}$. and $s = \frac{v^2}{2g}$.

336. Method of Determining the Distance a Body Falls during Any Particular Second.—If it be desired to find how far a body will fall during the tenth second, find how far it will fall during 10 seconds, then how far it will fall during 9 seconds; from the first subtract the second, and the remainder is the distance it will fall during the 10th second. To make this general, suppose it is desired to find the distance fallen during the t-th second. The distance fallen during t seconds is $\frac{1}{2}gt^2$, and during $t - 1$ seconds is $\frac{1}{2}g(t-1)^2$. $\frac{1}{2}gt^2 - \frac{1}{2}g(t-1)^2 = \frac{1}{2}g(2t-1)$, the distance fallen during the t-th second. That is, to find the distance passed through by a body falling from rest during any given second, multiply twice the number of seconds minus 1 by one-half of the acceleration due to gravity.

337. The Pendulum.—Fasten a small iron or lead ball to the end of a thread and attach the other end of the thread to a fixed point to serve as a support. The thread assumes a vertical position, and is in line with the direction in which the force of gravity acts. Pull the ball to one side and let go. The ball vibrates to and fro. This thread and ball constitute a pendulum. It can be seen that as the ball is drawn to one side, it must also be raised. When the hand lets go of the ball, the ball

begins to descend, but, on account of the string it cannot descend directly downward, but it descends as much as it can and its path is the arc of a circle of which the string is the radius. When the ball has reached its original position, it is as low as it can get, but, in falling to this position, the ball has acquired a velocity, and its momentum carries it past this lowest point and the ball begins to ascend on the opposite side. The ball continues to ascend on the opposite side until its motion has all been spent, when it again begins to descend and the operation is repeated.

In investigating the theory of the pendulum, it is convenient to make use of an ideal or simple pendulum which may be defined as a heavy material point suspended from a fixed point about which it is free to move, by a string without weight and incapable of stretching. Of course, no such pendulum actually exists.

All pendulums which do not comply with the conditions of an ideal or simple pendulum are called compound pendulums. Since there can be no string without weight and no material body without size, all pendulums in actual existence are compound. The nearest approach which can be made to a simple pendulum is to suspend a small metal ball by means of a fine thread.

338. Terms Defined.—A simple *Vibration* or *Oscillation* is the motion of the pendulum from one extreme of its swing to the other extreme. The term *vibration* is frequently used to denote a simple vibration.

The *Centre of Suspension* is the point of support about which the pendulum vibrates (C, Fig. 162).

A *Complete Vibration* is the motion of the pendulum from one extreme of its swing to the other extreme and back again (A D A or B D A B).

The *Amplitude of Vibration* is half the angle described by the swinging pendulum (angle A C B or B C D).

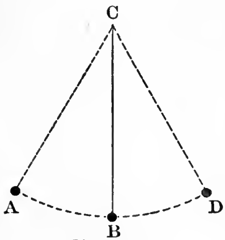


FIG. 162.

The *Period of Vibration* of a pendulum is the time required to make a simple vibration.

The *Rate of Vibration* is the number of simple vibrations made by the pendulum in one second.

339. The Rate of Vibration Depends upon the Length of the Pendulum.— Suspend two lead balls by means of threads of equal length so that the balls will hang side by side without touching. Cause them to vibrate so that the amplitude of one vibration is larger than that of the other. They both require equal times to make a vibration. Each successive vibration of a pendulum requires the same amount of time equal to that required by the preceding one. If, however, the pendulum be removed to a place where the force of gravity is greater, it will vibrate faster, but if taken to a place where the force of gravity is less, it will vibrate more slowly.

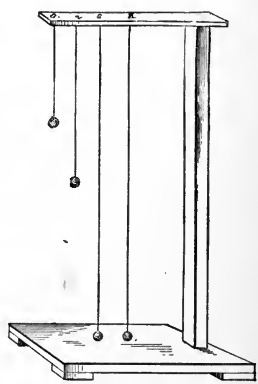


FIG. 163.

Suspend a third ball by means of a shorter thread and cause it to vibrate. The shorter pendulum vibrates faster than the longer one. It has been found that a pendulum 4 times as long as another pendulum vibrates half as fast, and one 9 times as long vibrates only one-third as fast.

340. The Law of the Pendulum.—The law of the pendulum is commonly expressed by the formula $t = \pi\sqrt{\frac{l}{g}}$ in which $\pi = 3.1416$, l = length of the pendulum, and g= the acceleration due to gravity. The development of this formula involves the use of higher mathematics, and hence would be out of place here. This formula contains three quantities, either two of which being known, the third can be found. Thus in any locality where g is known, the length of a seconds pendulum can be computed, or, if the length and g are known, the time of vibration can be found, and, if the time of vibration and the length are known, g can be determined. The length of a pendulum which beats seconds, when at sea-level in the latitude of New York City, is 39.1 inches.

341. Length of Compound Pendulum.—Most compound pendulums in use consist of a ball or bob suspended by means of a rigid rod. Since a short pendulum vibrates faster than a long one, the particles in its upper part are retarded by those below, and the particles below are accelerated by those above. But there must be one point which is neither accelerated nor retarded, that is, the acceleration given it by the particles above is counteracted by the retardation of the particles below it. This point is called the *centre of oscillation.* The distance from the centre of suspension to the centre of oscillation constitutes the theoretical length of the pendulum.

It has been ascertained that if a pendulum be suspended at its centre of oscillation, the rate of vibration is not changed; hence, the centre of suspension and the centre of oscillation are interchangeable. This fact furnishes the means of ascertaining the length of a compound pendulum.

Fig. 164 is that of a reversible pendulum with two movable weights, M and N, which can be so adjusted that the pendulum requires the same length of time to complete a vibration whether suspended at A or at B. This pendulum vibrates in the same time as the pendulum, S O, which consists of an iron ball suspended by a thread.

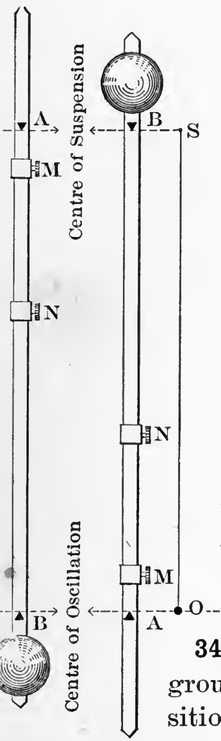


FIG. 164

342. Uses of the Pendulum.—The most familiar use of the pendulum is that of serving as a regulator of the motion of clocks. It also furnishes the most precise and most convenient way of measuring the force of gravity. The first experimental proof which showed that the earth is flattened at the poles was obtained by counting the vibrations of a pendulum in different latitudes. The United States Coast and Geodetic Survey uses the pendulum exclusively in all of its gravity work. The pendulum used by the United States is enclosed in an air-tight chamber from which the air can be exhausted to any pressure desired.

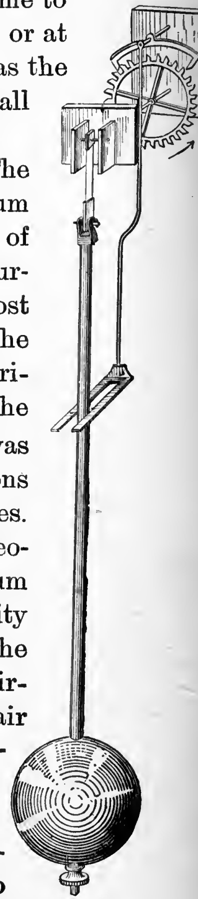


FIG. 165.

343. Inertia.—If a stone lie on the ground, it will remain in the same position until some force causes it to move If a book has been placed upon a desk and afterwards is gone, it is certain that its removal was due to some force.!! The book has no power of setting itself in motion. (Library U.C.!)

If a ball is already in motion, force is required to change the character of that motion. Force is required to make the ball move faster or to make it move more slowly, or to make it move to one side, or to stop it entirely.

When a ball is moving over any ordinary surface and force is no longer applied to it, the ball will soon come to rest. The force which resists or opposes the motion in this case is friction. If the friction is made very small by securing a smooth surface for the ball to roll upon, the ball will roll for a much longer time. The resistance of the air also helps to stop the ball. If it were possible to secure ice whose surface is perfectly smooth and flat, in a region where there is no air, a boy, moving rapidly along this surface, would not be able to stop himself. There would be no friction, either on the part of the ice or on the part of the air, to decrease the speed of his motion.

Every body continues in its state of rest or in its state of uniform motion in a straight line unless it is compelled by some force to change that state. Any change which a body may exhibit is at once the evidence of the existence of some force. *Force* may be described as anything which produces, or tends to produce, opposes, or changes motion in any manner. The inability of a body to start to move from a state of rest, or to change the character of its motion when it is already in motion, is called *inertia*.

344. Units of Force.—There are two systems of units used in measuring force: the *absolute units* and the *gravity units.*

In the gravity system the unit is the pound, or, when the metric system of units is used, it is the kilogram or

the gram. The pound and the kilogram or gram are the names of units used in measuring both mass and force. By the mass of a body is meant the amount of matter which it contains, not its weight. By its weight is meant the force with which it tends to move toward the earth. Mass and weight are not identical. The pound mass is the mass of a piece of platinum carefully preserved at the national capital. The force *pound* is the force of the attraction which the earth exerts upon a body on its surface whose mass is one pound. The *kilogram* is the force of the attraction which the earth exerts upon a body having a mass of one kilogram.

The mass of a body remains constant wherever the body may be placed, while the attraction of the earth for it varies with the latitude and altitude of the place where the body is located. A body if weighed at the equator would weigh less than if weighed at the poles, and its weight would be less on the summit of a mountain than at the base. If a body having a mass of one pound should be transported to the moon, and then to the sun, it would be found that the body is attracted on the surface of the moon by a less force, and on the surface of the sun by a greater force than on the surface of the earth. Since the force of gravity varies at different points on the earth's surface, the gravity unit also varies, and, for this reason, it is not suitable for precise scientific investigations.

Momentum has been defined as the quantity of motion of a body and is found by multiplying the mass of a body by its velocity. Change of momentum in a given time is proportional to the force which acts; therefore, the force may be measured by this change of momentum. A force

which in one second would give a body of ten pounds mass a velocity of 2 feet per second, would give a body of one pound mass a velocity of 20 feet per second.

A force which, if acting upon a mass of one pound for one second, will produce a change of velocity of one foot per second, is called a *poundal.* A force which, if acting upon a mass of one gram for one second, will produce a change of velocity of 1 centimetre per second, is called a *dyne.* These are *absolute* units whose values are *invariable.*

On the earth a body having a mass of one pound is said to weigh one pound. If this body be allowed to fall it will acquire in one second a velocity of 32.16 feet per second (g at New York City is 32.16 feet). Since the force of gravity acting upon a body of one pound mass for one second gives it a velocity of 32.16 feet per second, a force of one pound must be equal to 32.16 poundals. Therefore, to change pounds to poundals, multiply the number of pounds by 32.16, or g. Likewise, a body of one gram mass, when free to fall, acquires in one second a velocity of 980 centimetres per second. Hence a force of 1 gram is equal to 980 dynes. In each case it will be observed that one gravity unit is equal to g absolute units.

Let F represent the force, m the mass of the body, and a the acceleration; then, since force may be measured by change of momentum, which is the mass multiplied by the acceleration, we have the formula $F = ma$ (poundals or dynes).

345. Curvilinear Motion and Centrifugal Force. — One force may cause a body to move, but a second force, acting not in the same direction as the first, is necessary to cause the body to move in a curve.

When a stone is fastened to a string and whirled, a part

of the force exerted by the hand is used in urging the stone forward, while the other part is used in pulling the stone toward the hand. After the stone is once set in motion, very little force is required to keep it moving, since all of the resistance to be overcome comes from the air.

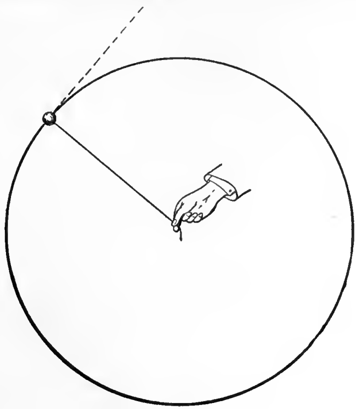


FIG. 166.

If the string, in any position, be cut by means of a very sharp knife, the stone will start away in a straight line which forms a right angle with the position which the string occupied the instant it is cut. Thus it can be seen that the stone is continually being pulled in toward the hand, in order to keep it from going away in a straight line. If the direction in which the stone actually moves is compared with the straight path along which the stone would move, if it were not continually pulled aside, it is seen that the pull of the hand practically moves the stone toward the hand. The outward pull which is experienced on whirling the stone about the hand by means of a string is called *centrifugal force*. The

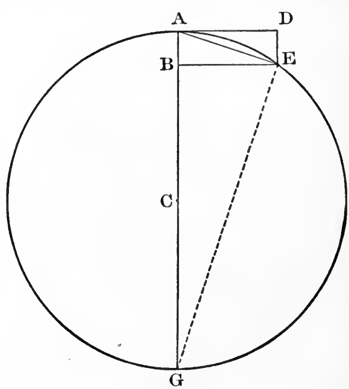


FIG. 167.

pull exerted by the hand is known as *centripetal force* and is equal to and opposite in direction to the centrifugal force.

Suppose a body to be moving in a circle of radius r with the uniform velocity v, so that in the space of time t it will have gone from A to E. Then arc A E $= vt$. In passing from A to E the body has been drawn aside from the straight path A D toward the centre C, a distance equal to D E (or A B). A uniform force tends to give a body uniformly accelerated motion (§ 334). Therefore, since the force pulling the body toward the centre is uniform, the acceleration given this body toward the centre must be uniform.

A B = the distance the body has been drawn aside from the straight path A D in time t. Therefore A B $= \frac{1}{2}\,at$ (§ 334). If t is taken very small, the difference in length between the chord A E and the arc A E becomes too small to be readily recognized; the chord A E and the arc A E may, for purposes of this discussion, be considered identical. By geometry it can be proven that the triangles A E G and A B E are similar.

$$\therefore \text{A G} : \text{A E} :: \text{A E} : \text{A B}.$$

A G, being the diameter, is equal to $2r$. A E, the distance passed over by the body with uniform velocity v, is equal to vt. A B, the distance moved due to the acceleration a toward the centre, is equal to $\frac{1}{2}\,at^2$. Substituting these values in the above proportion,

$$2r : vt :: vt : \tfrac{1}{2}\,at^2.$$

$$\text{Whence } v^2t^2 = \tfrac{1}{2}\,at^2 \times 2r,$$

$$\text{and } a = \frac{v^2}{r}.$$

$$\text{Substitute } \frac{v^2}{r} \text{ for } a \text{ in formula } F = Ma,$$

$$\text{Centrifugal force, or } F. = \frac{Mv^2}{r}$$

346. Work.—*Work* is the overcoming of resistance in producing or maintaining motion. The amount of work which a force (F) acting upon a body has accomplished, depends entirely upon the distance (s) the force has actually moved the body in opposition to some resisting force ($W = Fs$). A force may act, yet do no work, provided no motion results.

The unit of work used by English-speaking engineers is the *foot-pound*, which is the work done in moving a body one foot against a resistance of one pound. It is best illustrated as being the work done in lifting a pound weight through a vertical distance of one foot. All resistance to be overcome, however, does not consist in lifting weights against gravity. Work is done when a board is torn loose from the side of a house, or in drawing a body horizontally over the surface of another body.

The *kilogram-metre* is the work done in moving a body one metre against a resistance of one kilogram.

The absolute units of work are the *foot-poundal* and the *erg*.

The *foot-poundal* is the work done in moving a body one foot against a resistance of one poundal.

The *erg* is the work done in moving a body one centimetre against a resistance of one dyne.

Power.—*Power* in mechanics is the rate at which an agent can work. The *horse-power* is the unit of power and is that power which can do 33,000 foot-pounds of work in one minute, or 550 foot-pounds in one second. The horse-power was introduced by Watt so that the values of the engines could be compared with the work of horses. A horse cannot work quite at this rate, but a margin was allowed to prevent the mistake of making a

horse-power too small. A man can work at the rate of a little less than $\frac{1}{7}$ of a horse-power.

347. Energy.—Energy is the ability to do work. Boys have learned that an apple hanging beyond their reach on a tree can be brought to the ground by a stone or club. The moving stone possesses the ability to tear the apple loose from the tree and gravity then causes the apple to fall. The stone possesses the ability to do work because of its motion.

If a string be tied to a stone lying on a shelf and the string be passed over a pulley and fastened to a lighter object on the floor below, the stone, when free to fall, will raise the body from the floor. The stone by virtue of its position up on the shelf is able to perform work.

There are two types of energy, *kinetic* and *potential*. *Kinetic* energy is the energy of a body by virtue of its motion. *Potential* energy is the energy of a body by virtue of its position in reference to other bodies, or of the relative position of its parts. Any body elevated above the surface of the earth, a coiled or bent spring, or any elastic body changed from its natural shape possesses potential energy. In fact, a body possesses potential energy if any condition is present which is capable of producing motion in that body, such as strain, gravitative separation, chemical separation, and electrification.

348. How Energy is Measured.—Energy can be measured only by the work it can do, therefore the units of energy are the same as the units of work.

Suppose a body of a mass of m pounds start vertically upward with a velocity of v feet per second, then the distance (s) it will rise is $\frac{v^2}{2g}$. The work done in raising a mass of m pounds s feet is ms foot-pounds. But $s = \frac{v^2}{2g}$

(§ 335). Multiplying both members of this equation by m, we have ms (the kinetic energy of the mass) $= \frac{mv^2}{2g}$. Therefore representing the kinetic energy by $E, E = \frac{mv^2}{2g}$ foot-pounds.

It has been shown that when a constant force acts upon a body with mass m producing acceleration a, that $F = Ma$ poundals or dynes. Representing the distance by s, the work done is Fs foot-poundals or ergs. But $s = \frac{v^2}{2a}$. Multiplying $s = \frac{v^2}{2a}$ by $F = Ma$, member by member, we have Fs (the kinetic energy of the mass) $= \frac{mv^2}{2}$. Hence $E = \frac{1}{2} mv^2$ foot-poundals or ergs.

349. Conservation of Energy.—If a body be projected vertically upward against gravity, it has kinetic energy sufficient to lift its weight a certain height depending on the strength of the projecting force. As the body rises, its kinetic energy is expended in overcoming the resistance of gravity, until when it comes to rest, the whole of its kinetic energy has been expended, or rather changed into potential energy. By virtue of the work done on the body during its ascent, it has, at the instant of coming to rest, an amount of potential energy equal to the amount of kinetic energy expended in lifting it to the height attained. It then falls with uniformly accelerated motion, changing the potential energy into kinetic, and acquires more and more kinetic energy, until, at the instant it reaches the point from which it was projected, it has the same amount of kinetic energy as when it started up—that is, an amount sufficient to lift its own weight to the height from which it fell.

At the beginning of the ascent, and at the end of the

descent, the body had the same amount of kinetic energy; at the end of the ascent, and the beginning of the descent, it had only potential energy.

At any point of the ascent it had enough potential energy to lift it to the height already attained, and enough kinetic energy to lift it the remainder of the height yet to be attained. At any point of the descent it had enough kinetic energy to lift it back to the point from which it started to fall, and enough potential energy to lift it from the lowest point of fall to its present position. The sum of kinetic and potential energies remains constant.

A body in motion on the earth's surface will sooner or later come to rest after the propelling force ceases to act, because the motion of every body on the earth is opposed by friction. What has become of the energy of the moving body? It has been transformed into heat. A bullet, fired against a stone, is stopped by the stone. The bullet is warmed by its impact against the stone.

When a mechanical engineer examines a dynamo for the first time, he cannot understand why so much driving power is needed to make the armature rotate. He sees that the friction of the bearings and of the brushes against the commutator is so small that it can absorb but a small part of the energy delivered by the engine. Some cause other than friction alone must be looked for. It is found in the fact that, when the wires of the armature cut the lines of magnetic force, a resistance or drag is experienced by the wires, and the energy required to overcome this drag is converted into the energy of an electric current.

That heat is a form of energy can be seen in a locomotive drawing a train of cars. Here it is the heat from the

burning coal that supplies the engine with the required energy.

That an electric current is a form of energy can be seen in any city when an electric car is passing down the street. In the locomotive it is the heat, in the electric car it is the electric current which is transformed into mechanical motion.

Energy which is apparently lost is merely transformed into some other form. When it is transformed into heat, the heat may be radiated away into space and become lost or *dissipated*, but it cannot be annihilated. Neither can energy be created. This can be summed up as one of the greatest conceptions of modern science, namely the *conservation of energy. Energy can be transformed from one form into another, but the sum total of all the energy in the universe remains constant.*

350. Machines.—Of all animals man alone makes use of devices for the advantageous application of force. Such devices are known as machines. Machines are so designed as to employ force for the attainment of a desired result. By their use man can do work which otherwise would be impossible. He is also thus enabled to employ forces of nature, such as the force of the wind, the energy of running or falling water, the energy in fuel, and the strength of other animals. Machines have been devised for utilizing even the force of the tides and the heat of the sun.

The force which is applied to a machine is called the *power;* and the resistance to be overcome is called the *weight.* You cannot get more work out of a machine than is put into it, because energy cannot be created. In reality there is no machine in which there is no friction,

and, as a result, no machine turns out as much *useful* work as is put into it. Some of the energy is transformed into heat which is radiated away, and, as far as utility is concerned, may be considered wasted. The ratio of the useful work done by the machine to the total work done upon the machine is known as the *efficiency* of the machine.

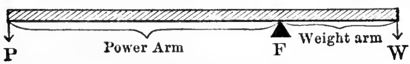
To find the work done by the power, it is necessary to multiply the power by the distance through which it moves. To find the useful work done, multiply the weight by the distance through which it is moved. If a machine could be made in which there were no friction, we should have a *perfect machine.* In such a machine the work done by the power is equal to the work done upon the weight. In the discussion of machines they will be considered as perfect. Hence, we can deduce the general law of machines: *The power multiplied by the distance through which it moves is equal to the weight multiplied by the distance through which it is moved.*

If the machine under consideration has any parts which bear the same ratio to each other as the ratio of the distance through which the power moves to the distance through which the weight is moved, the power and the weight can be respectively multiplied by the dimensions of these parts. For illustration, if both the power and the weight move in circles, the power multiplied by the radius (or diameter) of its circle is equal to the weight multiplied by the radius (or diameter) of its circle.

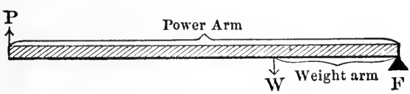
From the general law of machines it can be seen that the faster the power moves as compared with the weight, the greater is the weight which can be moved. Hence, greater force on the weight can be had at the expense of speed, while greater speed can be obtained at the expense of force. In practice, when the weight is a body

moved against resistance, a little additional power is required to impart motion to the body and also to the parts of the machine which partake of motion. After the required speed has been established, then the power and weight bear the relation to each other as suggested in the general law of machines.

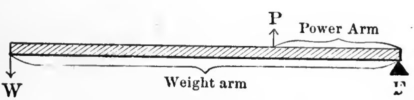
351. Simple Machines.—Every machine, however complicated it may be, is but a combination of one or more of the *simple machines*, or *mechanical powers*. There are six simple machines—the lever, the wheel and axle, the pulley, the inclined plane, the screw, and the wedge.



Lever of the first class.
FIG. 168.



Lever of the second class.
FIG. 169.



Lever of the third class.
FIG. 170.

352. The Lever.—The lever is a rigid bar free to move about a fixed point or axis called its *fulcrum*. The part of the lever between the power and the fulcrum is called the *power arm*. The part of the lever between the weight and the fulcrum is called the *weight arm*.

There are three classes of levers. A lever of the *first class* is one in which the fulcrum is between the weight and the power. In a lever of the *second class* the weight is between the power and the fulcrum. In a lever of the *third class* the power is between the weight and the fulcrum.

353. Law of the Lever.—*The power multiplied by its distance from the fulcrum is equal to the weight multiplied by its distance from the fulcrum.*

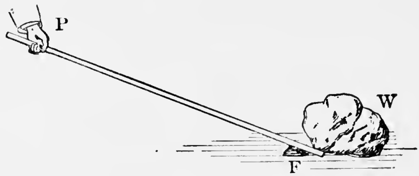


FIG. 171.

In the case of the lever, the power and the weight move in circles with the fulcrum as the centre, the power arm being the radius of the circle whose circumference is traversed by the power, and the weight arm being the radius of the circle whose circumference is traversed by the weight. Since the ratio of the radii of these circles is the same as the ratio of their circumferences, it is clear that the law of the lever is derived from the general law of machines.

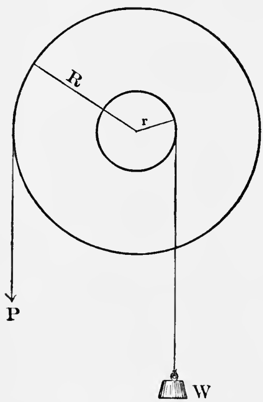


FIG. 172.

354. Wheel and Axle.—The *wheel and axle* consist of a wheel fastened to an axle so that they turn together. The power is applied to the circumference of the wheel, and the weight is fastened by means of a cord to the circumference of the axle.

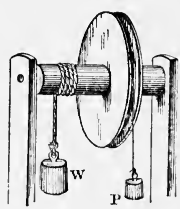


FIG. 173.

The power passes over a distance equal to the circumference of the wheel in the same time that the weight passes over a distance equal to the circumference of the axle. Hence, *the power multiplied by the circumference* (*or radius*

or diameter) of the wheel is equal to the weight multiplied by the circumference (or radius or diameter) of the axle.

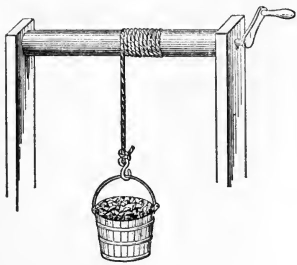


FIG. 174.

Instead of a wheel a crank may be used, as in a windlass. Sometimes the wheel and the axle do not have the same axis, as when motion is communicated from wheel to wheel by means of belts or cogs.

355. The Pulley.—A pulley consists of a wheel free to turn about an axis. The wheel is usually placed within a frame called the *block*. If, while the power is acting, the block is stationary, the pulley is said to be *fixed;* if the block moves, the pulley is said to be *movable*. The rope or string which passes over the wheel of the pulley has the same tension at every point.

In a single fixed pulley (Fig. 175), the weight and power move equal distances; hence the power is equal to the weight. There is no gain of either force or speed, but merely a change of direction of the force applied.

If a continuous cord pass about a movable and a fixed pulley (Fig. 177), the movable pulley sustaining the weight is supported by two parts of the cord, and the power must pass through twice the distance passed over by the weight. The weight, therefore, is equal to twice the power. If the

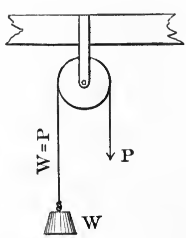


FIG. 175.

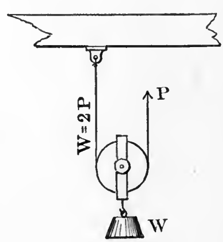


FIG 176.

cord pass about one movable and two fixed pulleys, the pulley sustaining the weight is supported by three parts of the cord and the power must pass through three times the distance passed over by the weight. Therefore, the weight is equal to three times the power. In a similar manner it can be shown that, when one continuous cord is used, the power must pass over a distance as many times greater than the distance passed over by the weight, as there are parts of the cord sustaining the weight. Hence, the law of the pulley: *The weight is equal to the power multiplied by the number of parts of the cord sustaining the weight.*

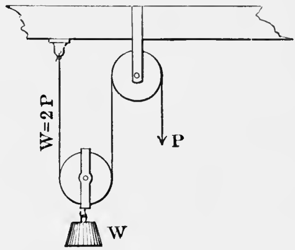


FIG. 177.

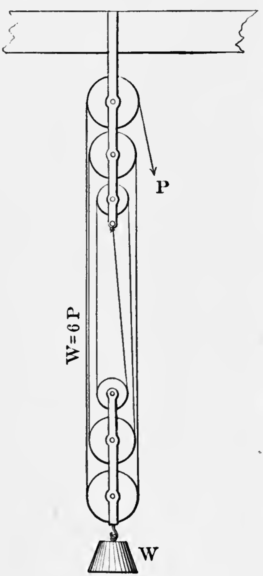


FIG. 178.

356. Inclined Plane.—Any surface inclined to a horizontal surface is an inclined plane. In rolling a barrel into a wagon, it is much easier to roll the barrel on a plank having one end on the ground and the other end resting on the wagon so as to form an inclined plane, than it is to lift the barrel vertically into the wagon. A part of the weight of the barrel produces pressure on the plank, while the rest of its weight tends to make it roll down the plank to the ground. All the force which is required is that needed

to overcome the tendency of the barrel to roll down the inclined plane. (The steeper the plank the greater must be the force required to roll the barrel into the wagon.) If the plank is in a vertical position this force must be equal to the weight of the barrel.

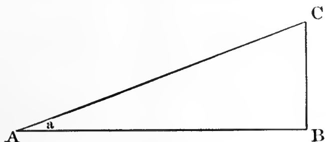


FIG. 179.

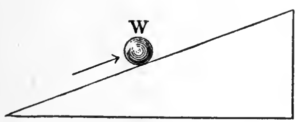


FIG. 180.

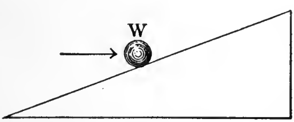


FIG. 181.

In Fig. 179, A C is the length of the plane, B C the vertical height, A B the base, a the angle of the plane.

In the inclined plane the power must move over the entire length of the plane, while the weight is raised the vertical distance from the foot of the plane to the top. Hence, *the power multiplied by the length of the plane is equal to the weight multiplied by the vertical height of the plane.*

If the power acts in a line parallel with the base, the power must act over a distance equal to the length of the base of the plane while the weight is raised the vertical distance from the foot of the plane to the top. Hence, *when the power is applied in a line parallel to the base, the power multiplied by the base is equal to the weight multiplied by the vertical height of the plane.*

357. The Wedge.—If it is desired to raise one end of a stone block, this can easily be accomplished by forcing an inclined plane under that end of the block, as shown in Fig. 182. This is the principle of the *wedge*, which

has usually the form of a double inclined plane with the bases placed next to each other. The law of the inclined plane, where the power is applied parallel to the base, applies also to the wedge; but, since the wedge is usually driven by percussion, it is difficult to apply any law other than that the smaller the angle of the planes the greater is the weight which can be overcome.

The wedge is of great service in

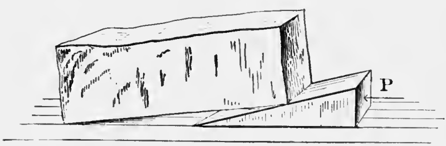


FIG. 182.

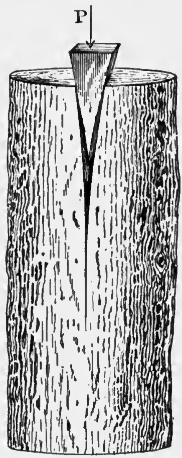


FIG. 183.

splitting wood and in raising great weights short distances, such as raising ships, separating layers of rock, etc.

358. The Screw.—The *screw* consists of a cylinder with

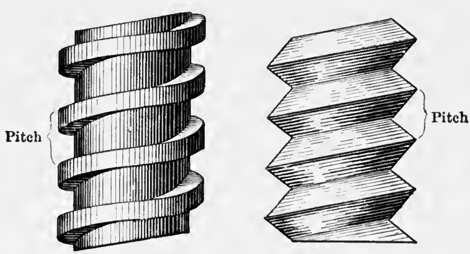


FIG. 184.

a rib or thread passing spirally around it. The principle involved is that of the inclined plane, as can be shown by

cutting a piece of paper in the shape of a right triangle and wrapping it around a lead pencil (Fig. 185). The hypotenuse of the triangle traces out the path of the thread. The distance between two contiguous turns of the thread measured along the axis of the cylinder is known as the *pitch* of the screw. The screw works in a block on the inside of which are threads corresponding to those of the screw. This block is called the *nut.*

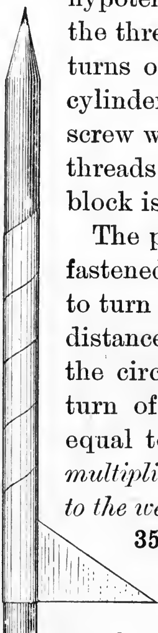


FIG. 185.

The power is usually applied to a wheel or lever fastened to the upper part of the screw. In order to turn the screw once, the power must pass over a distance equal to the circumference of the wheel or the circle of which the lever is the radius. In one turn of the screw the weight is raised a distance equal to the pitch of the screw. Hence, *the power multiplied by the circumference of the wheel is equal to the weight multiplied by the pitch of the screw.*

359. The Great Importance of Mathematics in Modern Physics.—Modern Physics rests upon the mathematical development of the ideas of momentum, force, energy, work, power, and other similar quantities. While it is possible to get an insight into many physical and chemical problems without their use, they are the foundations upon which must be built all further progress. The mathematical development of these ideas is, therefore, the first care of any larger work on physics. It is hoped the more ele-

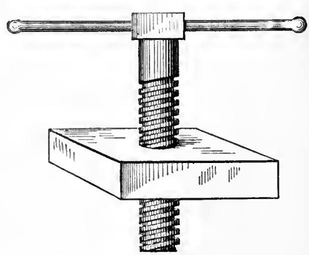


FIG. 186.

mentary work here presented will encourage students to undertake the more advanced work based upon this mathematical foundation.

EXERCISES

1. Is it possible ever to make a perpetual motion machine? Why?
2. If a stone be dropped from the top of a high monument, the stone will fall a little to the east of the vertical line. Explain.
3. Why cannot a man lift himself up by stepping into a bushel basket and lifting on the handles?
4. Why is a bicyclist apt to fall if he attempts to turn a corner rapidly when the street is slippery?
5. When a train starts, a passenger can feel his body pressing harder against the back of the seat. Explain.
6. When a marksman shoots at a target, does the bullet travel in a straight or curved line? Explain.
7. If a ball be fired from a cannon pointing vertically upward, will it fall back into the mouth of the cannon?
8. How can a driver make it easier for his horses to draw a heavy load up hill?
9. If a large hole were made extending from one side of the earth through the centre to the opposite side and a ball were dropped into this hole, what would become of the ball?
10. Why does the mud fly off of your shoe when you kick?
11. Why do fast revolving grindstones often break?
12. Why is more coal consumed in running a train a given distance in which numerous stops are made than is consumed by the train in running the same distance without stops?
13. Why is it so difficult to hold out a heavy weight at arm's length?
14. What effect has the placing of a live fish in a bucket even full of water upon the weight of the bucket and its contents?

15. A stone dropped into a well strikes the bottom in 3 seconds. How deep is the well?

16. A man can pump 200 lbs. of water per minute to a height of 16 feet; how many foot-pounds of work does he do in an hour?

17. A twenty H. P. engine is employed to pump water from the bottom of a mine 400 feet deep. How many cubic feet of water will it raise in 24 hrs.? (1 cu. ft. of water = $62\frac{1}{2}$ lbs.)

18. What force is required to roll a ball weighing 300 lbs. up an incline having a vertical rise of 10 ft. to every 100 ft. of the incline, when the force is applied parallel to the plane? When it is applied parallel to the base?

19. How far will a body, starting from rest, fall during the first second? During the eighth second?

20. What is the kinetic energy of a stone of 10 lbs. mass moving with a velocity of 15 ft. per sec.? What is the momentum of the stone?

21. What weight can be raised by a force of 100 lbs. by means of one fixed and one movable pulley?

22. What is the length of a pendulum beating half seconds at a place where the seconds pendulum is 39.1 inches?

23. The pitch of a screw is $\frac{1}{2}$ inch. The length of the lever used in turning the screw is 2 ft. What power must be applied to produce a pressure of one ton?

24. The radius of the wheel is 2 ft. and of the axle 4 in. What weight can be raised by a power of 50 lbs.?

25. A body of mass 2 lbs. is attached to the end of a string a yard long, and is whirled round at an uniform rate, making twenty revolutions in a minute. What is the tension in the string?

26. A force of 30 dynes acts for 10 seconds upon a body resting on a smooth horizontal plane, and imparts to it a velocity of 100 centimetres per second. What is the mass of the body?

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